EXPERIMENTAL PHYSICS

FRESHMAN COURSE

BURGESS

From Geo. K. Burgess

EXPERIMENTAL PHYSICS

A COURSE FOR FRESHMEN

Being a Revision of Alexander's Manual

BY

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PREFACE.

This manual represents the latest step in the development of a course in physics for Freshmen at the University of California under the direction of Professor Slate; the modifications of previous texts are not radical, but reflect the present instructor's views of what is suitable for the freshman class at this time. There is no serious claim to originality, either in subject matter or in method of presentation, both of which are largely those of the late Professor Whiting, and of Dr. A. C. Alexander, who, until recently, gave the instruction in this course.

The course has been modified by decreasing the time of instruction in the laboratory from two three-hour periods a week to two periods of two hours, and instead of one lecture there are now two recitations a week. By this change it is hoped that the students will get a better grasp of the principles involved in the experiments.

Among the main points by which this manual differs from its predecessors are the following:—

Because the laboratory period has been reduced from three to two hours, some of the exercises have been shortened.

The details of a considerable number of exercises differ from those of previous texts, and many of the experiments have been entirely rewritten, although treating in general of the same principles as heretofore, with a few exceptions.

More emphasis is given to the graphical representation of results.

Where possible, the principle of an experiment is summarized in an equation by the student.

Optional experimental parts of an exercise have been removed, due to the shorter laboratory period, and also because in practise this has been found by the author to be of questionable benefit in large elementary classes for which the ratio of the number of students to the number of instructors is great.

In place of the optional portions are put questions or problems that the student may solve outside of the laboratory, if he finishes the experimental part only in the regular period.

Questions are occasionally appended to an exercise that require a knowledge of principles developed in the class room, or reference to some standard descriptive work.

Finally, the exercises have been arranged in four groups of eleven

each, the exercises of each group being so written that the student, with the aid given in the recitations, may intelligently begin with any one. Although in certain instances there is an apparent lack of sequence, yet, on the whole, this system seems more efficient than the one previously in vogue, in which the students were started by eights in succession, when in a section of eighty students some were six weeks late in starting. By the new arrangement two weeks are gained in every eight, when all the students may devote their time to back work.

The author is indebted to the members of the Physical Department for helpful advice, and especially to Mr. C. A. Kraus, who has aided in many ways the preparation of these notes.

GEORGE K. BURGESS.

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GENERAL DIRECTIONS.

Beginning Work.—The class will be divided into four sections, each having two laboratory periods per week of two hours, preceded by a recitation, for which each section will be divided into halves.

The laboratory work includes forty-four exercises, divided into sets of eleven. As soon as registered, each student will report at the laboratory in East Hall and will be assigned to one of the first eleven experiments. He will then perform in succession at the following exercises the cycle of eleven experiments. Example: A student assigned to the 7th experiment will perform the first eleven in the order 7, 8, 9, 10, 11, 1, 2, 3, 4, 5, 6. Two weeks will be allowed at the close of this cycle for the correction and completion of work. A new set of experiments will then be mounted, and it will then be impossible to reperform any of the first eleven experiments this year.

In the Laboratory.—The following directions are necessitated largely by the size of the class.

Students will work in pairs and may choose their partners. Each student however will be required to take a separate set of observations for each experiment and to write up his notes independently. All data must be recorded at the time of observation in the note-book and not on scrap paper.

In general, at least three independent observations of each quantity measured are to be taken and *every* observation recorded when it is taken. Notes are to be neatly arranged (see sample note-book) and observations recorded so as to be distinct from descriptive or other written matter, and when practicable results should be tabulated.

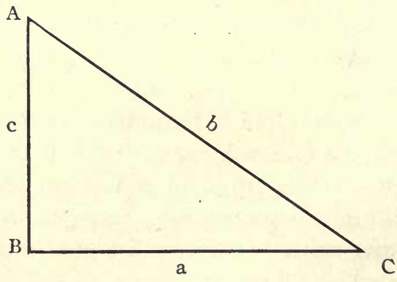
Concise but clear answers are wanted to questions asked; all inferences should be in the words of the student, and demonstrations should be complete. Fractions are to be expressed as decimals, and calculations given in detail.

For the heading of sheets, name, date, etc., consult sample note-book; the arrangement there indicated must be exactly followed. Separate sheets of a single exercise are to be fastened securely together; turned over corners will not be accepted.

PLOTTING.—In several exercises the results are to be expressed graphically on plotting paper. When the data permits, such scales for plotting should be chosen as will give a line extending diagonally across the paper. Observed points on the curve should be indicated by crosses and not by dots or circles. The known quantity is to be plotted horizontally and the quantity to be studied, vertically. Plots should be carefully drawn and properly labeled. In general, a smooth line drawn among the points corresponding to observations best represents these observations. For further details of construction of a plot, see sample note-book.

PROBLEMS.—A certain number of problems will be assigned during the year. They are to be worked on laboratory paper and the carbon prints are to be handed in.

TRIGONOMETRICAL RELATIONS.—For those students who are not familiar with the elements of trigonometry, the following definitions will suffice.



Consider a right-angled triangle ABC of sides a, b, and c. The various trigonometrical functions are most conveniently defined in terms of the parts of such a triangle.

The sine (written sin) of an angle is the ratio of the opposite side to the hypothenuse.

$$\sin A = \frac{a}{b} \text{ and } \sin C = \frac{c}{b}.$$

The cosine (written cos) is the ratio of the adjacent side to the hypothenuse.

$$\cos A = \frac{c}{b} \text{ and } \cos C = \frac{a}{b}.$$

Evidently also

$$\cos A = \sin C \text{ and } \sin A = \cos C.$$

$$a = b \cos C = b \sin A, \; c = b \cos A = b \sin C.$$

The tangent (written tan) is the ratio of the side opposite to the side adjacent.

$$\tan A = \frac{a}{c} \text{ and } \tan C = \frac{c}{a}.$$

Also

$$\tan A = \frac{\sin A}{\cos A} \text{ and } \tan C = \frac{\sin C}{\cos C}.$$

For very small angles the sine and tangent may be replaced by the angle itself.

UNFINISHED WORK.—At the close of a laboratory period the student will present the carbon print of his notes to the instructor, and if the exercise has not been finished, the records will be stamped with the date, and the exercise may be completed later, but is to be handed in complete within two weeks after the date last stamped upon it, otherwise it must be repeated. All experimental data taken out of the laboratory must be stamped.

In general, a student will have ample time to complete the experimental part of any exercise in a laboratory period; but if pressed for time, calculations, inferences, demonstrations, and answering of questions may be performed outside of the laboratory, as above indicated. No experiments which are taken home and for which the data have been changed will be accepted. Corrections are to be made in the manner indicated in the sample note-book.

GRADES.—The following system of marking will be used:—

1. Excellence.
2. Satisfactory.
3. Deficient in inferences, proofs, or answers to questions.
4. Repetition of part of experimental work required.
5. Repetition of whole exercise required.

Unsatisfactory work will be returned for correction. All deficient exercises are to be raised to grade 2, otherwise the grade INCOMPLETE will be given for the term's work.

ORDER AND BREAKAGE.—Those working at any exercise will be held responsible for the apparatus used and will be expected to leave it in good order when through. Breakages should be reported to the instructor.

GROUP I.

In some of these experiments mercury is used. Care must be taken not to spill it, and all metals should be kept away from it. Refer to the sample note-book for suggestions as to arrangement of data and writing of notes. In general, seek to finish the experimental work in the time allowed, leaving computations and answers to questions to be done outside of the laboratory if pressed for time.

1. LIQUID PRESSURE AND DENSITY.

I. Clamp a U-tube in a vertical position to a burette stand, with the bend of the tube resting on the table. Pour into this tube enough mercury to stand about 5 cm. above the table in each arm. Then pour into the longer arm enough water to stand about 13.6 cm. above the end of the mercury column. Work out all air bubbles with a fine wire, and mop up any water resting on the mercury in the short arm with a bit of blotting-paper tied to the end of the wire. Measure the heights above the table of the ends of the mercury and water columns, measuring as nearly as possible to the center of the meniscus in each case. Are the liquids in the two branches at the same level? If not, why? What differences are there between the shapes of the free ends of the two columns? Account for these differences.

Find the length of the mercury column that balances the water column, and also the ratio of the two balancing columns (water column to mercury column).

II. Fill the longer arm of the U-tube nearly full of water, and measure the length of the water column, and also of the mercury column that balances it. Find again the ratio of the balancing columns. Is it the same as in I? This ratio will be shown to be equal to the specific gravity of mercury.

III. Fill one of the two beakers, or jars, with water, and the other with a saline solution. Place a leg of an inverted Y-tube in each of the liquids Cautiously draw the liquids up in both legs by suction, and close the stem of the Y air tight. Why is the liquid higher in either branch than in the corresponding open vessel? Measure the height of each column of liquid above the level of the liquid in the open vessel. Is it the same for both liquids, or not? Why?

Does it make any difference if the branches of the Y-tube are not of the same diameter, or are not held vertically?

Calculate the specific gravity of the saline solution.

IV. Fill the two branches of a W-tube, one with water and the other with wood-alcohol. This should be done by pouring the liquids into them alternately, a small quantity at a time. Why is it necessary to observe this precaution in filling?

Make the proper measurements and calculate the specific gravity of the wood-alcohol. Draw diagram in illustration.

Why is it unnecessary to have the ends of the columns at the same level?

V. Answer the following questions:—

1. To what class of liquids is the method of the U-tube inapplicable? Why?

2. In the case of highly volatile liquids, what advantage has the method of the W-tube over that of the Y-tube?

3. Which of the three do you consider to be the most general method?

VI. Distinguish between specific gravity and density.

If pressure is defined as force per unit area, form an equation expressing the equality of pressures of the two liquids in the arms of the U-tube and show that the heights are inversely as the densities; and that when water is used in one arm, the ratio of the heights is the specific gravity of the other liquid. Show that for a liquid, pressure is proportional to depth.

VII. Calculate the total outward pressure of a cube of mercury 20 cm. on a side. What is the weight of this mercury?

2. VAPOR PRESSURE AND DALTON'S LAW.

I. Take a closed tube, at least 80 cm. long, and wipe it clean and dry with a swab tied to a long and stiff wire. Then fill it with mercury by means of a small funnel.* Close the open end with the thumb and invert the tube in a reservoir of mercury. After removing the thumb, does the mercury in the tube fall to the same level as the mercury in the reservoir? If not, why What is meant by the barometric pressure?

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*Observe the following directions in filling the tube and removing air bubbles:—

Fill to within a couple of cm. of the open end. Close with the thumb and invert a number of times, gathering all the air bubbles adhering to the sides into one large bubble. Then hold erect and fill completely, pouring the mercury in slowly and working out all air bubbles with a fine wire. Again invert in the reservoir. (The amount of air in the tube can be observed by tilting it until the closed end is about 70 cm. above the table.) To further remove the air, place the thumb tightly over the open end of the tube while in the reservoir, and then raise and carefully invert it a number of times, letting the partial vacuum pass slowly from one end of the tube to the other, and finally, holding it erect with the open end up, take the thumb off and fill completely, as directed above. This operation should be repeated until the air bubble seen when the tube is tilted has been reduced to the smallest possible size. The height of the mercury column ought now to agree, within one cm., with the barometric reading for the day. If it does not so agree, repeat.

Measure the height of the mercury in the tube above that in the reservoir. Is it the same as the height of the barometer? If it is not, explain why.

II. Having measured the height of the mercury column above the level of the mercury in the reservoir, draw as much ether as possible into a medicine dropper, and, inserting it into the reservoir under the open end of the tube, introduce a few drops into the tube, taking great care not to introduce any air. Introduce enough so that some of the liquid will remain unevaporated on top of the mercury column. Describe in detail what takes place when the ether is introduced. Does the ether all evaporate, or does it cease to evaporate after a certain amount has been introduced? Explain why. When is a vapor said to be saturated?

After waiting 10 minutes for the ether vapor to come to the temperature of the room, measure the height of the mercury column. Why is it less than before the introduction of the ether? What do you find to be the pressure of the ether vapor, in cm. of mercury, at the temperature of the room? (Record this temperature.)

III. (*a.*) Pour more mercury into the reservoir, leaving enough space for the mercury in the tube when it is taken out. With the tube resting on the bottom of the reservoir, measure again the height of the mercury column, and also the length of the tube occupied by the ether vapor.

(*b.*) Raise the tube so that its lower end is just below the level of the mercury inthe reservoir and after a few minutes repeat the measurements of (*a*).

(*c.*) Answer the following questions:—

1. Was the pressure of the ether vapor in (*a*) the same as in (*b*)?

2. Was its volume the same?

3. The temperature being kept constant, do you find the pressure of saturated ether vapor to depend on its volume, or not?

IV. Remove the ether from the mercury by wiping its surface with a piece of clean blotting-paper and then passing it through a pinhole at the point of a paper filter. Pour the mercury into a 150-cm. bottle with a rubber stopper, to a depth of 2 or 3 cm. Be sure that the bottle is clean and dry and free of ether vapor. (If there is any ether vapor in the bottle, it can be removed by inserting a tube and blowing it out.) Insert the short arm of a U-tube, at least 50 cm. long, through the rubber stopper. See that the stopper fits closely into the mouth of the bottle and press it in as tightly as possible. Invert the bottle, taking care not to entrap any air in the mercury column. Resting the bend in the tube on the table, measure the height of the mercury in the tube above, or below, its level in the bottle. Four ether into the tube so as to stand in an unbroken column 15 or 20 cm. deep, and attach a rubber bulb to the open end of the tube. By pressing the bulb, force a little of the ether into the bottle, taking care not to force in any air. What is the effect of introducing the ether?

V. Force in about 15 cm. of the ether in the tube so that the ether in the bottle is at the same level as the mercury had been before, or a trifle above this level. The volume of the mixture of air and ether vapor being approximately the same as the volume of the air before the introduction of the ether, how does the pressure within the bottle compare with the pressure when it contained air alone? Did the evaporation cease immediately after the introduction of the gasoline, as in III? If it did not, explain why. What do you find to be the effect of mixing ether vapor with air, the volume being kept constant?

Watch the mercury column and see that its height becomes constant before taking the measurements in VI. The mercury ought to become stationary in 15 minutes.

VI. Find by appropriate measurements the increase of pressure within the bottle over the pressure before the introduction of the ether. What does this increase of pressure represent? How does it compare with the pressure of ether vapor when unmixed with air as determined in II?

Observe and record the temperature of the room. Is it the same as when II was performed? How would any difference in temperature affect the pressure of the ether vapor?

According to *Dalton's law* the pressure of any vapor, or gas, in a gaseous mixture* is the same as it would be if it occupied the space alone. Do the results obtained in VI and in II tend to confirm the truth of this law?

VII. Calculate in dynes per square centimeter the barometric pressure, also the pressure of the ether vapor in II, in the same unit.

Is evaporation a cooling or a warming process? Explain.

3. VARIATION OF VAPOR PRESSURE WITH TEMPERATURE.

I. Fill a deep hydrometer jar with water at about 55°. When the water has cooled to 48° (not before) set in the jar a closed U-tube with a few cm. of ether, free of air bubbles,† in the closed end, and at least 50 cm. of mercury in the rest of the tube. The mercury before inserting in the water should stand a few cm. lower in the open arm than in the closed, and there should be enough water to completely cover the ether. Describe what takes place when ether is warmed in this way.

Suspend a thermometer in the jar on a level with the ether and read the temperature of the water.‡ At the same time measure

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* Dalton's law does not apply to a mixture of gases, or vapors, that act on each other chemically, or to a mixture of vapors from liquids that are mutually soluble.

† If there is any air above the ether, ask to have it removed.

‡ To read a thermometer accurately, the observer's eye should be placed so that the first degree mark below the top of the mercury coincides with its reflection in the mercury. The fraction of a division above this mark should be carefully estimated and recorded in tenths of a degree.

the difference in level between the mercury in the two arms of the U-tube. Do this as accurately as you can by placing a metre rod against the side of the jar and sighting across the top of each mercury column. It will injure the rod to put it into the water. Using this last measurement and the barometric pressure for the day, find the pressure, in cm. of mercury and in dynes per square centimetre, of the ether vapor within the closed arm of the tube. Stir thoroughly when taking readings.

II. If necessary, siphon off a small quantity of the water and replace it with enough cold water to lower the temperature about 3 or 4 degrees, not more. Repeat the measurements of the last section.

In this way make a series of some ten observations of the temperature and pressure of the ether vapor, cooling it down to the temperature of the room or lower.

III. Plot the results of I and II on co-ordinate paper and draw a smooth curve to show the relation between the pressure and temperature of ether vapor.

Do you find the pressure of the ether vapor to vary uniformly with the temperature or not?

IV. Take some ether in a small test-tube and immerse it in water at about 30°, adding hot water gradually until the ether begins to boil. A small, clean tack or other sharp-pointed object placed in the ether will facilitate boiling. Record the temperature of the ether when it first begins to bubble as the boiling point.

Find from the plot obtained in III the temperature of ether vapor when its pressure is equal to the barometric reading for the day. How does this agree with the boiling point of ether just found? What relation may one infer exists between the temperature at which a liquid boils and that at which the pressure of its vapor becomes equal to the atmospheric pressure? Explain.

V. Write not less than one hundred words on the properties of saturated vapors. Explain the phenomenon of boiling.

4. BOYLE'S LAW AND VOLUMENOMETER.

I. With the Boyle's law apparatus take a set of five readings of pressure and of corresponding volumes, covering the range of the apparatus. To the difference in mercury levels what quantity must be added to give the total pressure on the inclosed gas? Assuming the tube to be of 1 cm. section, plot applied pressures, *i. e.*, the difference in mercury levels, in terms of reciprocals of volumes. What does this plot show to be the relation between the pressure and volume of a gas when the temperature is constant? Produce the line drawn until it cuts the pressure axis and compare the intercept on the pressure axis with the barometer reading.

II. Unscrew the iron cap of the volumenometer and by raising or lowering the open tube adjust the level of the mercury in the other tube to some point between the middle and the upper marks. See that the iron cap is empty and replace it, screwing it down air-tight.

Test the apparatus to see that it is air-tight. (Describe how you do this.)

Notice that there are three horizontal marks on the closed tube and that the mass of mercury that fills this tube between each pair of marks is recorded on the apparatus, so that the volumes between the marks may be calculated. The density of mercury is 13.6. Find the volume of the air enclosed above the middle mark by noting the change in volume when the mercury is set at the upper and at the middle marks and also the accompanying change in pressure. Two equations may thus be formed, one giving the difference in volumes between the upper and lower marks and the other the ratio of these two volumes (in terms of the ratio of the pressures).

Write these equations and find volume called for.

III. Introduce a piece of iron into the iron cap and find as in II the volume of the inclosed air to the middle mark. Calculate

the density of the piece of iron, after finding its mass, explaining the process you use and writing out the equations.

IV. Repeat II and III, using the middle and lower marks, and compare results.

5. PRESSURE OF GAS AT CONSTANT VOLUME.

I. Set a metre rod in a vertical position alongside the open tube of a simple constant-volume air thermometer with a fixed bulb. Fill the space about and above the bulb with water at about 5° or 10°, and *stir continuously.* Allow ten minutes for the inclosed air to come to the temperature of the bath, and then raise or lower the open tube so as to bring the mercury in the stem of the bulb to the bottom of the tube through which the stem is thrust. Read on the metre rod the heights of the two mercury columns, and take the temperature of the bath, stirring all the while.

II. Draw off some of the water and replace it with warmer water so as to raise the temperature of the bath about 10°.* After waiting ten minutes, repeat the operations and measurements of I.

In this way make a series of observations on the pressure and temperature of the inclosed air, raising the temperature about 10° at a time,—and carrying it as high as can be conveniently done with boiling water. Arrange the results in tabular form. How did the pressure of the inclosed gas (air) alter as its temperature increased? Was the rate of change uniform?

III. Calculate the average increase in pressure for a rise of one degree in temperature. If no observation was made at 0°, calculate from your results, using the atmospheric pressure for the day, the pressure that the gas would have at 0°, if its volume was kept

* Do not try to obtain a rise of exactly 10° in temperature. Better results can be obtained and time saved if the bath is raised a trifle over 10° and then stirred till the inclosed air has had time to come to the same temperature as the surrounding water, whatever that may be.

constant. Find the ratio of the average increase in pressure per degree to the pressure at 0°.

Calling P_0 the pressure at 0°, P_t the pressure at t°, and a the ratio just found, write the equation connecting the pressure and temperature of a gas when the volume is constant.

IV. Plot the results of II, plotting the temperatures as abscissæ and the pressures as ordinates.

Draw the straight line that agrees most nearly with the points located on the plot. Find the rise of this line (*i. e.*, the increase in pressure of the gas) for the change of 100° in temperature, and also, from the plot, the pressure of the gas at 0°. From these calculate the ratio of the increase in pressure per degree to the pressure at 0°. How does this agree with the result found in III? Why should this last be the more reliable of the two results?

V. What would be the pressure of a gas at—273° C., supposing there was no change of state or volume? If the pressure of a gas depends on the motion of its molecules, would the molecules have any motion at—273° C.? Then, as heat is the energy due to molecular motion, according to this reasoning could a gas be cooled below—273° C.?

This temperature is called *absolute zero.* The temperature measured in Centigrade degrees from absolute zero is called the *absolute temperature.*

6. EXPANSION OF GAS UNDER CONSTANT PRESSURE.

I. Fill the space about the closed tube, or bulb, of the air thermometer with ice-cold water. Set the slider at the zero of the vertical scale, and adjust the mercury columns so that the mercury in both tubes is at the level of the lower end of the stuffing box. (The mercury column can be set quite accurately by sighting across the end of the brass tube surrounding the glass.) Read the volume of the inclosed gas (air) and take the temperature of the water bath, stirring thoroughly.

II. Raise the temperature of the bath as in Exercise 5, II, about 10° at a time, and repeat for each temperature the operations and measurements of I, waiting ten minutes between successive temperatures to allow the air to take on the temperature of the bath. What was the pressure of the inclosed air in each case? Was it the same? Was the expansion of the air uniform? Arrange the results in tabular form.

III. Calculate the average expansion for a rise of one degree in temperature. If no observation was made at 0°, calculate from your results the volume that the gas would have had at 0°. Find the ratio of the average expansion per degree to the volume at 0°,—in other words, the *cubical coefficient of expansion* between 0° and 1°.

Calling V_0 the volume of a gas at temperature 0°, V_t the volume at t°, and a the coefficient just found, write the law of expansion of a gas at constant pressure in the form of an equation. This is called the *law of Charles* or *Gay-Lussac.*

IV. Plot the results of I and II on co-ordinate paper, plotting the temperatures as abscissæ and the volumes as ordinates.

Find from this plot, by the method of Exercise 5, IV, the expansion for a change in temperature of 100° and the volume of the gas at 0°. Calculate from these the coefficient of expansion between 0° and 1°. Is the result the same as that obtained in III?

V. When experiments 4, 5 and 6 have been performed, hand in a paper of at least two hundred words on the properties of gases.

7. SPECIFIC HEAT.

I. Weigh out about 300 gr. of lead shot and heat it in a double boiler. After the water begins to boil, stir the shot thoroughly with a wooden paddle, continuing until the temperature of the shot becomes constant.

Have ready about 75 gm. of water (weighed to 0.5 gm.) at a temperature of 5° to 10°, in a calorimeter of known mass.

Note carefully the temperature of the shot (stirring) and of the water (stirring), and as quickly as possible pour the shot into the water, stirring vigorously all the while and note the rise in temperature of the water. Read the temperature of the mixture every half minute for five minutes, counting from the instant of mixing.

From the results obtained calculate:—

1. The number of heat units gained by the water, using as heat unit the calorie or the heat required to raise the temperature of one gramme of water one degree.

2. The number of heat units lost by the shot (in terms of s, the specific heat of lead) or the ratio of the heat required to raise 1 gm. of lead one degree to that required to raise 1 gm. water 1°.

Assuming that the shot and water are alone concerned in the transfer of heat, what relation exists between the heat lost and gained by the shot and water respectively? Write the equation representing this relation and calculate the specific heat of lead.

II. Calculate from this result, using above equation, the mass of water which would have brought the mixture to a temperature two degrees higher than that of the room.

Repeat I, using this mass of water and the same amount of shot as before and other conditions also the same as in I.

Why should the latter result be the better?

III. The result found in II is to be corrected for the heat lost to cup, assuming the specific heat of the cup to be 0.095; and also corrected for radiation as follows:—

Construct a plot with times as abscissæ and temperature of water and mixture as ordinates; project the line (which should be straight if the stirring has been thorough), representing the temperatures of the mixture, back until it cuts the ordinate at the instant of mixing. This ordinate will be approximately the true temperature of the mixture. Why?

Write the complete equation involving all of the above quantities and recalculate the specific heat of lead.

IV. If the water at the start had a temperature higher than that of the room, would the value of s found have been high or ow? Explain.

If one gramme of water were spilt in stirring, what would be the effect on the value of s?

8. LATENT HEAT.

I. Weigh out in a metal cup, which has been previously weighed, at least 500 gm. of water at about 30°. After recording the exact temperature of the water, take a piece of ice (about 100 gm.) and place it in the cup, first wiping it carefully with damp cotton. Stir the mixture thoroughly and take its temperature just as the ice disappears.

Having previously weighed the water, the mass of the dry ice used can be found by weighing the mixture and subtracting the mass of the water.

II. Calculate in order the following quantities, using the same unit of heat as in Exercise 7:—

1. The heat lost by the water surrounding the ice.

2. The heat lost by the cup. (In calculating this quantity it will be sufficiently accurate to take the specific heat of the metal as 0.095.)

3. The heat required to raise the water from the melted ice from 0° to the temperature of the mixture.

4. The total heat absorbed by the ice in melting.

5. The heat absorbed by each gramme in melting.

The latter quantity is called the *latent heat of fusion* of water.

III. Fill a small copper boiler about two-thirds full of water and insert through the cork stopper a safety-tube with an opening about 2 cm. from its lower end. Connect to the boiler a rubber tube with a trap for collecting the water condensed in the tube and a delivery-tube 4 or 5 cm. long. Bring the water in the boiler to a boil. (If at any time steam issues vigorously from the

safety-tube, it means that the water is low and the boiler needs refilling.)

Weigh out about 500 gm. of ice-water in a metal cup of known mass, and take its temperature. Empty the water out of the trap and hold it so that the end of the delivery-tube is immersed in the ice-water. Stir and observe the temperature as it rises. When the temperature reaches a point two-thirds as much above the temperature of the room as the original temperature of the ice-water was below, remove the delivery-tube. Stir and take the temperature again carefully. Replace the cup on the balance, and find the increase in the mass of the water due to the steam that has been condensed.

IV. If the temperature of the water was two-thirds as much above the temperature of the room after the condensation of the steam as it was below before the introduction of the steam, we may safely neglect the effect of the air and surrounding bodies, for the cup will lose to the room, by radiation and conduction, as much heat in the latter part of the experiment as it gains from it in the first part. Using the same unit of heat and the same value for the specific heat of the metal cup as in II, calculate in order the following quantities: —

1. The total amount of heat imparted to the water and the cup.

2. The heat given out by the water from the condensed steam in cooling from 100° to the temperature of the mixture.

3. The total amount of heat given out by the steam or water vapor in changing from the state of a vapor to that of a liquid.

4. The heat given out by each gramme of water vapor in changing from the gaseous to the liquid state.

The latter quantity is called *latent heat of vaporization* of water.

5. Write the equations representing this experiment.

V. Write at least one hundred words on the phenomena of fusion and evaporation.

9. MECHANICAL EQUIVALENT OF HEAT.

I. Take two bottles and put in each of them a kilogramme of lead shot. Place these bottles in a mixture of ice and water.

When the shot in one of the bottles has cooled about 3° below the temperature of the room, shake it thoroughly, and pour it into the tube provided, about one metre long, and close the end of the tube securely after taking the temperature of the shot by inserting a thermometer. Raise the end of the tube containing the shot with sufficient velocity to keep the shot from falling, and when it reaches a vertical position, let the shot fall vertically, like a solid mass, through the length of the tube. Repeat this again and again, keeping count of the number of times the shot falls.*

After the shot has fallen through the length of the tube a hundred times, insert a thermometer through a side opening, and take its temperature again. Why has the temperature of the shot risen above that of the room?

II. Replace the shot in the ice-water to cool, and while the tube is still warm, repeat the operations and measurements of I, using the shot from the other bottle, which should be about 3° below the temperature of the room. (Its temperature can be raised by shaking the bottle, if it is too low.) Repeat the experiment in this way, cooling one bottle of shot while using

* PRECAUTIONS, ETC.—The shot should not be raised too suddenly, so as to throw it violently against the side of the tube, nor should the tube be raised or lowered so as to lengthen or shorten the distance fallen through by the shot.

It is well, also, to hold the tube about a foot from each end, so that there is no danger of any heat being imparted to the shot from the hands. The following method of raising the shot and reversing the tube is recommended: Lay the tube on the table, and raise the end containing the shot, while the other end rests on the table. Let the shot fall, and then lower the raised end. Raise the other end, which now contains the shot, and let the shot fall again. Then lower this end, and again raise the end which contains the shot; and so on.

the other, making five determinations and using the average result in what follows.

III. Remove the stopper and measure the distance from the inner end of the stopper to the top of the shot. What is the average distance fallen through by the shot in each reversal of the tube? Explain. In one hundred reversals? How far would the shot have to fall to raise its temperature one degree? How far would one gramme have to fall to raise its temperature the same amount (one degree)? How much work, in ergs, would be required to raise one gramme of shot one degree in temperature? The specific heat of lead is about 0.032. Using this, calculate, in the ergs, the amount of work necessary to raise one gramme of water one degree in temperature. This last quantity is called the *mechanical equivalent* of the heat unit.

IV. Write the equation representing this exercise.

What are the chief sources of error in the experiment?

V. Power is the rate of doing work, and may be measured in ergs per second, or in watts, which is 10^7 ergs per second. 10^7 ergs is a joule. Calculate the work done in joules by the shot falling 100 times the length of the tube, and if this operation akes 3 minutes, calculate the power developed in watts.

10. SURFACE TENSION.

It is of capital importance that the rectangles and beakers used in this exercise be *clean.* They should be thoroughly washed in hot water before being used and for every change from one liquid to another.

The Jolly balance should be read by bringing a definite point, as the lower end of the spring, in a horizontal line with its image in the mirror. The reading is facilitated by bringing a card pierced with a small hole (3 mm. in diam.) close before the eye and standing in front of the scale at such a distance that the object and image are seen sharply focused at the same time.

I. Fill a beaker, about 7 cm. in diameter, with a solution of

soap in water. Replace the pans of a Jolly balance by a wire rectangle 2 cm. wide, hung vertically, and hold the beaker so that the rectangle is immersed to a certain definite depth in the soap solution. See that there is no soap film within the rectangle, and read the balance.

Let the rectangle dip in the soap solution so that a film is formed within it. Raise or lower the beaker so that the rectangle is immersed to the same depth as before and again read the balance. What difference does the presence of the film make in the reading of the balance? To what force is the elongation of the spring due?

Take four independent sets of readings.

II. Repeat the measurements of I, using rectangles about 4 and 6 cm. wide. How do you find the tension of the film to vary with its width?

III. Find the elongation of the spring produced by a small known weight,—some fraction of a gramme. How does the elongation vary with the force producing it? Test this.

Calculate the tension in dynes (980 dynes = weight of one gramme) of each of the three films in I and II. As a film has two surfaces, the width of the surface in apparent tension, neglecting that about the wires, will be equal to twice the width of the rectangle. Using this, calculate in dynes the average tension of the soap solution across each cm. of the surface.

The tension across a unit length of the surface of a liquid is called the *surface tension* of that liquid.

IV. Clean the beaker and rectangle thoroughly, and repeat the measurements of II with water fresh from the faucet.

As a film can not be formed with pure water, take the reading of the balance when the upper side of the rectangle is just above the surface of the water and again when it breaks away from this surface. The force measured in this way may be regarded as due entirely to surface tension, although this is not strictly true. Take four sets of readings.

Calculate the surface tension of the water. How does it compare with that of the soap solution?

V. Using the same rectangle, find the surface tension of hot water from the heater at the sink. Does the temperature affect the surface tension appreciably, and how?

VI. If the rectangle 4 cm. wide carries a soap film 2 cm. high, what is the work done in forming this film? What is the energy per square centimeter of this film? How does this quantity compare with the surface tension?

11. PRINCIPLE OF MOMENTS.

I. (*a*.) Attach a light metal frame to the table so that it can rotate freely about a pivot. Fasten two spring balances to the frame with twine, at equal distances on opposite sides of the center, and draw them out so that they are parallel. Read the balances. Does a force produce the same effect if transferred along its line of action? How test this?

Pull one of the balances out until the tension is doubled, keeping them still parallel. What does the other balance register? When a force tends to produce rotation about a pivot, what is the effect of doubling this force upon the force opposing the rotation?

(*b*.) Move one of the balances to a point twice the distance from the center as in (*a*) and pull it (parallel to the other balance) until it registers the same tension as before. Read both balances.

The perpendicular distance from the center of rotation to the line of action of a force is called its *lever arm*. When a force tends to produce rotation about a point, what do you find to be the effect of doubling the lever arm upon the force opposing the rotation?

(*c*.) The tendency of a force to produce rotation about a point, according to (*a*) and (*b*), is proportional to the product of what two quantities? This product is called the *moment* of the force about the point considered, and is usually taken positive in sign when the force tends to produce rotation in a counter-clockwise direction, and negative when it tends to produce rotation in the opposite direction.

II. (*a.*) Take a beam suspended so as not to rub the surface of the table, and connect its middle point to a nail in the table by means of a spring balance. Attach two balances to two screw-eyes, one metre apart, on the opposite side of the beam at unequal distances from its middle point and to corresponding nails in the table. Tighten the cord attached to the first balance. Read all three balances, and measure the distances between their points of attachment to the beam.

(*b.*) Loosen, or tighten, the cords a little and read the balances again.

(*c.*) Calculate the moment of each of the forces in (*a*) about some point of the beam. Give these moments their proper signs, and find their algebraic sum. Do the same for the forces in (*b*). What is your conclusion as to the value of the sum of their moments when a number of parallel forces in the same plane act on a rigid body so that it is held in equilibrium?

III. Attach three balances at random to the frame used in I, and to nails in the table. Tighten the cords and read the balances. Draw, on a sheet of paper laid underneath the frame, a line parallel to the line of action of each of the forces measured by the balances. Remove the frame and measure carefully the lever arm of each force about the pivot as a center. Calculate the moments of the forces about the pivot and find their algebraic sum. In addition to finding the sum of the moments about the pivot, find also the sum of the moments of the forces about some point outside the pivot. Do you find the sum of the moments to be approximately the same wherever the center of moments is taken, or not? Explain.

IV. Repeat III, removing the pivot, so that the frame is free to move in any horizontal direction. Make the proper measurements and calculate the sum of the moments of the forces about some point on the table taken at random. Do the same for some other point on the table. Do you find the sum of the moments to be approximately the same wherever the center of moments is taken?

V. If any number of forces in the same plane act upon a rigid body so that it is held in equilibrium, what do you conclude from the results of this exercise must be the algebraic sum of their moments about any point in that plane? The correct answer to this question is called the *principle of moments.*

VI. Two equal, parallel forces in opposite directions constitute a *couple.* The perpendicular distance between them is called the *arm* of the couple.

Let a be the arm, and F one of the component forces of a couple. Find the moment of this couple about any point. Is it the same for all points? Demonstrate this for any point within and one without the lines of action of the forces.

GROUP II.

In general, students will begin with the exercise corresponding to that they began with in Group I. Thus he who started with the 5th exercise will now take the 16th, and so on.

12. COMPOSITION OF FORCES.

I. Take a stout beam, over a metre long, and find its weight (in lbs.) by means of a spring balance.

Attach cords of equal length to screw-eyes near the ends of the beam, and suspend it by these cords from two 30-lb. spring balances hung from nails in the wall, at the same distance apart as the screw-eyes in the beam. Read the balances. What relation exists between the combined readings of the balances and the weight of the beam?

II. Suspend a mass of metal, weighing over 30 lbs., from the middle of the beam and read the balances again. Do the balances read alike? Why? How can you find the weight of the metal from the readings of the balances? What is the weight as thus found?

III. Hang the mass of metal from a point to one side of the middle of the beam and read the balances again. Why do they not read alike now? Does the relation found in I between the total suspended weight and the combined readings of the balances still hold true? Measure the horizontal distances from the cord by which the weight is hung to the cords to which the balances are attached. How do the products formed by multiplying each distance by the reading of the corresponding balance (less one-half the weight of the beam) compare?

In general, what is the resultant of two parallel forces in the same direction equal to: what is its direction: and how is its line of action situated with reference to the component forces?

IV. Hang two 30-lb. spring balances from two nails above the blackboard, at least one metre apart, and connect the balances by a cord somewhat over a metre long. From the middle point of this cord suspend the mass of metal used in II and III. Draw on the blackboard lines parallel to the two parts of the cord and lay off on these lines, from their intersection, lengths proportional to the tension in each part of the cord as registered by the proper balance. Construct a parallelogram with these lines as sides and draw the vertical diagonal. Measure the length of this diagonal in lbs., using the same scale as was used for the sides of the parallelogram. How does this diagonal compare in direction and length with the downward force (weight) of the mass suspended from the cord? What is the value of the weight as found by this method?

V. Hang the mass of metal to one side of the middle of the cord, and construct another similar *parallelogram of forces*. Is the relation between the diagonal and the weight of the suspended mass the same as in IV? What is the value of the weight as found from this parallelogram?

VI. Hang the mass of metal by a single cord from one of the nails. Attach a spring balance to the cord, near the bottom of the blackboard, and pull it horizontally one foot from the vertical. Note the reading of the balance, and measure the vertical distance from the nail to the line of action of the horizontal force.

By what two forces was the cord acted upon, and in what direction was their resultant? Which one of these two forces was measured directly? Find the value in lbs. of the other force. (As the two forces are at right angles, this may be done either graphically by constructing a *triangle of forces*, or by calculation from similar triangles.) Find also the tension in the inclined part of the cord.

VII. Repeat VI, drawing the cord two feet to one side instead of one foot and find again the value of the weight.

VIII. If three forces are in equilibrium about a point, show that they may be represented in magnitude and direction by the three sides of a triangle taken in order.

13. ELASTICITY: LAWS OF STRETCHING.

I. (*a.*) Attach a spring balance to the finer of the wires hanging freely from the ceiling. Set the scale immediately behind this wire and adjust the index on the wire, if necessary, until this index is opposite the upper part of the scale, and read its position on the scale by means of a lens, taking care that the index, lens, and eye are in a horizontal line. Read the spring balance also.

(*b.*) Hang on a weight—putting it *gently* into place—and repeat (*a*). Add successively three other weights, noting the index and balance readings in each case.

(*c.*) Remove the weights one by one, taking the same readings as in (*b*) and (*a*). Average the corresponding results of (*a*), (*b*), and (*c*).

(*d.*) Find the length of wire used, measure its diameter in four places and compute its mean cross-section.

II. Clamp the wire used in I at about midway its length and repeat I, taking care to use the weights in the same order as before.

III. With a wire of greater diameter but same material, repeat I, noting the precautions of I and II.

IV. Make a plot of the results in I with weights in dynes

(453.6 grammes are equivalent to a pound Avoirdupois) as abscissæ and elongation of the wire as ordinates. What relation do you find to exist between the stretching force and the resulting elongation? The statement of this relation is known as *Hooke's Law.*

V. (*a.*) Show from I and II the relation between the length and elongation.

(*b.*) From I and III, show the relation between the diameter and elongation; between the cross-section area and elongation.

(*c.*) Form an equation giving the elongation in terms of length, cross-section, force applied, and a constant K.

VI. Stress is defined as force per unit area; strain is the elongation per unit length; and the measure or *modulus of elasticity* is the ratio of the stress to the strain. Find the expression for the modulus of elasticity in terms of the quantities in V and calculate its value in C. G. S. units for the substance used. What relation exists between the modulus M (called Young's Modulus) and the constant K in V (*c*)? Is the value of M the same for all substances? (Compare results with your neighbors' who used wires of different material.)

VII. If a very considerable weight were hung on a wire, would the conclusions of IV, V, and VI hold? Explain. Why does no correction have to be made for the position of the spring-balance?

14. ACTION OF GRAVITY.

I. (*a.*) Find the time of a quarter-vibration by counting and timing 100 complete vibrations of a rod pendulum freed from any weights that may have been attached to it.

(*b.*) Fasten a strip of impression paper, dark side out, and on it a piece of white paper, to the lower end of the pendulum. Suspend a metal ball by a thread passing over two nails above the pendulum, another at the base, and attach to the lower end of the pendulum, pulling the latter aside. The weight of the ball and

friction will be sufficient to hold the pendulum aside. Burn the string near the ball after it is at rest and find by trial to what height the ball must be raised so as to hit the paper when falling. Make three determinations of this distance, measuring from the center of the ball above to the corresponding mark on the paper in each case.

II. Clamp the weight provided to the pendulum near the lower end at the place marked and repeat I (*a*) and (*b*).

III. Repeat with the weight clamped near the top of the pendulum.

IV. (*a.*) Find in each of the above cases, for the time of a quarter vibration, the average velocity of the ball, and its final velocity. Show that the final velocity is twice the average velocity if the ball starts from rest and increases its velocity at a constant rate.

(*b.*) Deduce from the results of I, II, and III the relation between the space passed over by the ball and the time, indicating clearly the process you use.

(*c.*) Calculate the distance the ball would have passed over in one second, averaging the results of I, II, and III.

(*d.*) Show to what power of the time the acquired velocity is proportional; see (*a*) and (*c*).

(*e.*) Calculate the velocity acquired in one second, *i. e.*, the acceleration (usually denoted by the letter g), averaging results as before.

V. (*a.*) Express IV (*b*) in the form $S=Kt^x$ and calculate the value of the constant K. What relation does it bear to the value of g? What then is the equation for the space passed over in terms of the time and acceleration?

(*b.*) Similarly find the value of the constant in the relation found in IV (*d*) and write the corresponding equation.

(*c.*) Deduce the expression for the velocity of a body, starting from rest and moving under the action of gravity, in terms of the acceleration and space.

VI. If a ball of greater mass had been used, would the same results have been obtained for the final velocities and for the acceleration? Explain.

Distinguish between mass and weight.

15. THE PENDULUM. I.

I. (*a.*) With a metal ball attached to the longest wire that the apparatus allows, pulling aside the bob not more than 10 cm., find the period of the pendulum to 0.01 second by the following method:—

First find the approximate period* by timing about twenty vibrations. (Be careful to count "one" when the bob passes the middle of the swing at the *end* of the first vibration.) Next note the time that the bob passes to the right (say) through the center of swing, the eye being in line with this position; wait about three minutes and note again the time of transit in the same direction; repeat this timing two or three times. Between each pair of observations there was a whole number of vibrations. Divide the first interval by the approximate period found above; if this period were the true one the quotient would be an integer. Divide the interval by the nearest integer to the quotient last found and the result will be a closer approximation to the true period. Repeat this operation for the other observed intervals and take the mean as the best value for the period. (Note: The computations may be done after the whole experiment has been performed.) Measure the length of the pendulum, *i. e.*, from point of suspension to center of ball.

(*b.*) Repeat (*a*), pulling aside the bob not more than 5 cm.

(*c.*) Repeat (*a*), pulling aside the bob some 50 cm.

(*d.*) What is the effect of increasing the amplitude on the period of a pendulum? Which is the best value to take for the period, that given by (*a*), (*b*), or (*c*)? Why?

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*The period is the time of a complete vibration, or the time between two successive transits in the same direction.

II. (*a*.) Repeat I (*a*) or (*b*), using two shorter pendulum lengths.

(*b*.) Substitute a wooden ball of same size as the metal one and repeat, using any length of pendulum, but measuring it.

III. (*a*.) From I and II (*a*) find the relation existing between the length and period of the pendulum. Indicate clearly your method.

(*b*.) Show whether or not the relation III (*a*) applies to II (*b*). What is the effect on the period of changing the mass of the bob?

IV. From the results of I and II and the relation of III (*a*) calculate the length of the seconds pendulum at Berkeley. (A seconds pendulum is one whose half-period is one second.)

16. THE PENDULUM. II.

I. (*a*.) Find the period of the pendulum, to a hundredth of a second, when set so that it vibrates in a vertical plane. (See Ex. 15.)

(*b*.) Find the period when the plane of vibration makes an angle of $60°.35$ with the vertical. ($\cos. 60°.35=0.49$.)

(*c*.) Find the period when the plane of vibration makes an angle of $75°.5$ with the vertical. ($\cos. 75°.5=0.25$.)

(*d*.) What is the vertical force acting on the pendulum bob? What is the vertical force acting on unit mass of the bob? Suppose this vertical force acting on unit mass to be resolved into two components, one perpendicular to the plane of vibration of the pendulum, and the other in the direction of its length when at rest. If a pendulum is constrained to vibrate in a particular plane, as in this case, would a force perpendicular to its plane of vibration affect its period or not? Why? Draw a diagram showing forces acting on bob.

What is the ratio between the force per unit mass in the direction of the length of the pendulum in (*a*) to that in (*b*); in (*a*) to that in (*c*)? (Express these ratios as reciprocals.) What

is the ratio of the period in (*a*) to that in (*b*); in (*a*) to that in (*c*)? (Calculate these ratios in decimals.) By comparing these results, find the law connecting the period of a pendulum with the force on unit mass, or the acceleration, in the direction of its length when at rest, assuming that the period varies as some integral root, or power, of the acceleration.

II. (To be done when Ex. 15 has been completed.) (*a.*) From the law deduced in III (*a*) of Ex. 15 find the length of the simple pendulum equivalent to the physical pendulum of I (*a*), Ex. 16, using the seconds pendulum as comparison.

(*b.*) Express the period P of a simple pendulum in terms of a constant k, its length, L, and acceleration in the direction of its length. The latter quantity is g (see Ex. 14) if the pendulum vibrates in a vertical plane.

(*c.*) Calculate the values of g and of k as follows: The equation of II (*b*) applies to the case of the seconds pendulum of Ex. 15 and to the simple pendulum of II (*a*). Form two simultaneous equations for the values of k and g in terms of the known quantities L and P, for each pendulum, and solve for k and g.

III. Is the length of the seconds pendulum the same over the surface of the earth? Why? Write not less than one hundred words on the uses of the pendulum.

17. RESONANCE TUBE.

The resonance tube to be used consists of a long vertical glass tube connected at its lower end by a rubber tube and siphon with a jar of water, so that when the jar is raised and lowered, the water flows in and out of the tube. The siphon can be started by setting the jar on the floor and pouring water into the tube until it flows into the jar. The water in the tube may be kept at any desired level by turning the cock at the base.

Tuning forks are to be set in vibration by striking with rubber hammer, and *in no other way*.

I. Hold a vibrating A-fork over the nearly full tube, and mark

with a rubber band as the jar is lowered the level of the water when the air in the tube vibrates in unison with the fork and causes a marked increase in the intensity of the sound.

Raise the jar, and as the water rises readjust the rubber band to the level of the water when the sound swells out again. Let the water rise and fall past this point a number of times and determine the level when the air in the tube vibrates in unison with the fork, as accurately as you can, recording each measurement.

As the air has no freedom of motion in a vertical direction at the surface of the water, this plane where the column of air may be cut off without prejudice to its rate of vibration must be one of minimum vibration, *i. e.*, a *nodal plane*.

What is the condition of the air at the open end of the tube?

Find all the prominent nodal planes you can. Measure the distances between them and between the highest one and the open end of the tube. Is the latter the same as the distance between two consecutive nodal planes? Can you account for the fact that the ratio of these distances is not exactly 1:2? How are these distances related to the wave-length in air of the particular note sounded? Explain and draw diagram in illustration.

II. Repeat I with the two C-forks, and also with a G- or D-fork.

Find the ratio of the distance between the nodes when the A-fork was used to that when the large C-fork was used. This gives the ratio between the wave-lengths. How is this ratio related to the ratio between the vibration frequencies of the two notes? The latter ratio measures the *musical interval* between the notes.

Calculate from your results the musical intervals between the lower C-fork and each of the others.

III. If the larger C-fork makes 256 complete vibrations per second, calculate the velocity of sound in air in the tube used. Find the vibration number of each of the other forks.

IV. Explain why the column of air emits a note.

Is more or less energy used by the fork and air column sounding together than when the fork is sounding alone? Explain.

18. VELOCITY OF SOUND IN SOLIDS.

I. Clamp a long brass rod exactly at its middle point in a vice. Take a long glass tube, provided with a piston at one end and containing powdered cork, and set its rubber-covered end against one end of the rod. A cardboard disc of some ·2 cm. diameter should be glued to this end of the rod.

Set the rod in vibration by stroking it from the center out slowly and with but slight pressure, with a cloth wet with wood alcohol or rubbed with resin. The piston should be adjusted by trial until the cork-dust takes up its characteristic arrangement. Describe the behavior of the cork dust. Where are the nodes? The loops? Which is found at either end of the tube? Explain. Measure the length of the tube and find the wave-length of the sound in air. What is the wave-length of the sound in the rod? Explain. Make three determinations.

Calculate the ratio of the wave-length in brass to the wave-length in air for the same note. How is this ratio related to the relative velocity of sound in brass and air? Calculate the velocity of sound in brass,* and write out the equations involved.

II. Repeat the measurements of I with a glass rod and find the velocity of sound in glass.

III. Repeat with an iron rod.

IV. How with this apparatus might the velocity of sound in gases be found? Write the equations involved.

V. Write at least one hundred words on the subject of stationary waves.

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* The velocity of sound in air is:—

$V=331\sqrt{1+0.004t}$ metres per second, where t is the temperature in centigrade.

19. LAWS OF A VIBRATING STRING.

I. (*a.*) Attach two piano steel wires (No. 27 and No. 22 B. & S. gauge) to a sonometer and stretch the lighter wire over the sounding-board with a weight of 4 lbs. Move the sliding bridge until the note given out by the wire when plucked is in unison with the tuning-fork provided. (The note of the fork can be made more audible by holding the end of its handle on the sonometer board.) Measure the length of the vibrating part of the wire.

(*b.*) Move the sliding bridge so that the note given out by the wire is in unison with the note an octave* below that of the tuning-fork, and again measure the vibrating part of the wire.

(*c.*) What is the relation between the vibration frequency of two notes separated by an interval of an octave? What, by comparing the results of (*a*) and (*b*), do you find to be the law connecting the length of the vibrating wire (or string) with its vibration frequency?

II. With additional weights increase the tension of the wire to four times its tension in I, and adjust the sliding bridge, if necessary, so that the note given out is in unison with that of the tuning-fork. How does the length of the vibrating part of the wire compare in this case with its length in I (*b*)? What do you conclude to be the law connecting the vibration frequency of a stretched wire with its tension?

III. (*a.*) Repeat the experiment of I with the heavier wire, and by comparison with the result of I (*a*) find the ratio between the lengths of the two wires when their vibration frequencies are equal. From this find the ratio between the vibration frequencies of the two wires when their lengths are made equal? (See law found in I.)

(*b.*) Measure the length of a piece of each kind of wire and find the ratio of their masses per unit length, using a Jolly balance for weighing.

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*Two notes have an interval of an octave where one has twice the pitch of the other.

What do you find to be the relation between the vibration frequency and linear density of a stretched wire, the length and tension being constant?

IV. Form an expression for the pitch of a wire in terms of its length, tension and linear density. What does this equation assume regarding the elastic properties of the wire and the nature of its motion?

20. PHOTOMETRY.

I. Set a diffusion photometer,—two rectangular blocks of paraffine separated by a sheet of tin-foil,—so that the two blocks of paraffine are equally illuminated by the diffused light of the room. Light a set of four simple gas jets and a single separate jet of the same form, and regulate the flow of gas so that the jets are all of the same height and brightness. Place the single jet at a distance of 50 cm. on one side of the photometer, so as to illuminate one block of the paraffine, and the set of four jets on the other side at such a distance that the two blocks of paraffine will be equally illuminated. Measure the distance from the photometer to the four jets.

How does the illumination of the paraffine due to the single jet compare with that due to the four jets? How does the intensity of the illumination due to a single jet at 50 cm. compare with that due to a *single* jet at the distance of the four jets? The intensity of the illumination is proportional to an integral power of the distance; what, from your results, do you conclude the power in question to be? Is it direct or inverse?

II. Place the four jets at 50 cm. from the photometer and the single jet on the opposite side at such a distance that the blocks of paraffine are again equally illuminated. Are the conclusions drawn from the results of I corroborated, or not, by the results thus obtained? Record measurements.

III. Light a candle and place it at a certain distance from the photometer. Light a coal-oil lamp and place it on the opposite side of the photometer, so that the candle and lamp illuminate

the blocks of paraffine equally. (The height of the lamp wick should not be altered during the course of this experiment, and the lamp should burn at least five minutes before taking readings.) How can you find the ratio between the illuminating power of the candle and that of the lamp? (Take four readings with varying distances of the candle.) What is this ratio as derived from your measurements?

Weigh the lamp and the candle. Let them burn for 30 minutes. Reweigh and find the mass of the coal-oil and of the paraffine, or candle substance, consumed. For one gramme of matter consumed by the candle, how many grammes were consumed by the lamp? Calculate the relative illuminating power of coal-oil and paraffine for equal masses consumed, assuming that the illuminating power varies directly as the amount of matter consumed.

IV. Alter the height of the lamp flame and repeat III. Calculate again, from the result obtained, the relative illuminating power of coal-oil and paraffine for equal masses consumed. How does the value found compare with that found in III? Is the assumption made above, that the illuminating power varies directly as the amount of matter consumed, corroborated by the results of III and IV, or not?

V. Form an equation expressing the candle power of any source of light in terms of the proper variables. Distinguish between intensity of illumination and illuminating power.

21. REFRACTION.

I. Take a rectangular cell, having one side of plate glass and containing a mirror revolving on a vertical axis, and fill it about half full of water. Set this cell so that the axis on which the mirror revolves is over the center of a large circle drawn on the table. Adjust the cell so that its glass side is perpendicular to a radius of the circle drawn parallel to the end of the table. This may be done by stretching a white string along this radius, and

moving the cell until the image of the string in the plate glass coincides in direction with the string itself. (A piece of blackened tin held back of the plate glass will help in locating the image of the string.)

Move your eye along the edge of the table until you see the image of the string in the mirror above the water. With another white string locate the direction of this image, and stick a pin in line with it on the circle drawn on the table. In the same way look for the image of the string seen through the water, and mark with another pin on the circle the direction of this image.

Measure the perpendicular distance from each of these pins to the radius represented by the first string.

Answer the following questions:—

1. Does the light from the first string undergo any change in direction on entering the cell?

2. Will it, therefore, strike the mirror at the same angle within the liquid as without, *i. e.*, above the liquid?

3. Will it be reflected at the same angle within as without the liquid?

4. Will the reflected light, passing through the liquid, have the same direction after leaving the liquid as that which does not pass through the liquid? What do you find by experiment?

Remembering that the first string is perpendicular to the surface of the water at which the light is refracted, how are the sines of the angles of incidence and refraction related to the distances measured above?

The ratio of the sine of the angle of incidence to that of refraction when the light is incident in air, or, more properly, in a vacuum, is called the *index of refraction* of the substance. (If the light is incident in the substance and refracted in air, the index of refraction, on the contrary, is equal to the ratio of the sine of the angle of refraction to that of the angle of incidence.) Calculate from your results the index of refraction of water.

II. Repeat I with the mirror at a slightly different angle and calculate again the index of refraction of water.

III. Rotate the mirror a little more and repeat I, calculating again the index of refraction.

Do you find the index of refraction to vary with the angle of incidence, or not?

IV. Take a cubical block of glass and lay it on a sheet of brown paper. Mark on the paper the position of two of its opposite edges, and continue the lines with a ruler held against the face of the cube. Stick a pin in the table about 30 cm. from the cube, and as far to one side as it can be placed without becoming invisible when looked at diagonally through the opposite faces of the cube. Looking at this pin through the cube, place three pins in line with it, one on the same side close to the cube, and two on the side of the observer. Remove the cube and draw lines on the paper to show the direction of the light from the first pin before entering the glass, after passing through the glass, and within the glass. How did the direction of the light before entering the glass cube compare with its direction after passing through the cube?

Draw a perpendicular to the face of the cube through the point where the light entered, make the proper measurements, and calculate the index of refraction of the glass. Turn the cube through 180° and repeat.

V. How with the rectangular cell, if the dimensions of the apparatus permitted, might the critical angle for water be found? Explain, giving a diagram.

22. REFRACTION AND DISPERSION.

I. Set a mirror in a small rectangular cell, and fill it about half full of water. Place the cell with its glass side perpendicular to the line formed by a linear source of light (an electric lamp with "horseshoe" filament) and a narrow slit and at a distance of 100 cm. from the scale of a metre rod set at right angles to the line of the light and slit. Move your eye along the metre rod until the image of the light in the mirror above the water becomes

plainly visible and read the scale. Look in the same way for the image of the light in the mirror as seen through the water. Is this image similar in appearance to that seen above the water? Describe and explain the difference. Can you locate its direction, as was done for the image seen above the water?

Locate the direction of the extreme red of the spectrum seen through the water. As the distance of the scale from the cell is one metre (100 cm.), the respective readings of the scale in metres will be equal to the tangents of the angles of incidence and refraction. The source of light may be considered as at the surface of the mirror, hence the light is incident in the dense medium. Show by diagram the angles of incidence and refraction. Using a table of natural sines and tangents, find the sines corresponding to these tangents, and calculate the index of refraction of water for red light. (See Expt. 21 for definition of index of refraction.)

Find in the same way the index of refraction for blue light, using the extreme blue of the spectrum; and also for yellow light.

II. Repeat I with a saline solution instead of water. What effect do you find salt in solution to have upon the index of refraction of water?

The angle between the rays of red and blue light after refraction is called the *dispersion* for red and blue light. What is the dispersion for these rays for water and for the salt solution?

III. Show how from this experiment the velocity of light in the salt solution may be computed, if the velocity in water is known, and demonstrate the relation between the index of refraction and velocity.

GROUP III.

23. IMAGES IN A SPHERICAL MIRROR.

I. Place a concave spherical mirror so as to form as clear an image as possible of the window-sash on a screen, and measure the distance from the mirror to the screen.

Repeat, using some distant object, as the tops of the trees across the road, instead of the window-sash, and measure again the distance from the mirror to the screen. Was this distance greater or less than when the window-sash was focused on the screen? The *principal focus* is the point through which all parallel rays are reflected. Its distance from the mirror is called the *principal focal length* of the mirror. Which of the measurements above may be taken as the principal focal length of the mirror?

II. Place an upright rod at a distance in front of the mirror equal to twice its principal focal length. Adjust the position of the rod by the method of parallax, so that some definite point on it will coincide in position with its image in the mirror. Do this by adjusting the rod first so as to coincide with its own image*, and then sliding a piece of paper up or down the rod until it meets its image. This will give the required point on the rod. (Do not confound the image formed by the front, plane surface of the glass with that formed by the spherical mirror on the back.) What measurement will now give the radius of curvature of the mirror? Why? How does this compare with the principal focal length?

III. (*a.*) Place the screen at as great a distance from the mirror as the table will allow, and place two gas jets so that their images formed on the screen will be as distinct as possible. To obtain images beyond the center of curvature of the mirror, where did the gas jets have to be placed, between the mirror and the principal focus, between the principal focus and the center of curvature, or beyond the center of curvature?

(*b.*) Measure the distance from the mirror to the gas jets and the distance from the mirror to the screen; also the distance between the gas jets and the distance between their images.

*This can be done by changing the position of the observer's eye and adjusting and readjusting the position of the rod until it will always coincide in direction with its own image from every point of view.

How does the ratio between the first two distances compare with the ratio between the last two? Find the ratio between the distance of the object and that of its image from the center of curvature of the mirror instead of from its surface. How does this ratio compare with the other two?

(*c*.) Reduce to decimals the reciprocals of (1) the distance from the mirror to the gas jets; (2) the distance from the mirror to their images; (3) the principal focal length; (4) the radius of curvature. Of these four reciprocals find two whose sum is equal to a third, and also equal to a simple multiple of the fourth.

IV. Interchange the positions of the gas jets and the screen. (In the new positions they will, of necessity, have to be placed on opposite sides of a line normal to the mirror.) Adjust the screen so as to obtain as definite images as possible, and repeat the measurements of III (*b*). Does the proportion found in III (*b*) still hold true? Does the relation between the reciprocals in III (*c*) still hold true? When the gas jets are beyond the center of curvature, are the images formed between the mirror and the principal focus, between the principal focus and the center of curvature, or beyond the center of curvature?

V. Place a vertical rod between the mirror and its principal focus, within 8 or 10 cm. of the mirror, and locate its image by means of another rod, using the method of parallax. Measure the distance from the mirror to the object and its image respectively. In order that the relation between the reciprocals found in III (*c*) shall still hold true, what change in sign is necessary? Write the equations representing the conditions in III and V.

VI. Suppose an object at an infinite distance from the mirror; where would its image be found, and how would it change in position as the object approached the mirror, supposing the object to approach until it touched the surface of the mirror? State whether the image would be real, or virtual; erect, or inverted; larger than the object, or smaller.

24. CONVEX LENSES.

I. (*a*.) With a convex lens form an image of the window-sash on a screen and measure the distance from the lens to the screen.

(*b*.) With the same lens form an image of some distant object on the screen, and measure again the distance from the lens to the screen. Is this distance the same as in (*a*)? Which of these distances may be taken as the principal focal length of the lens? Why?

II. Light two gas jets and place them at a distance from the lens equal to twice its principal focal length, and place the screen so as to form as distinct images of the jets as possible. Measure the distances respectively from the lens to the screen, and from the lens to the gas jets. How do these distances compare? Measure the distances between the gas jets and between their images. How do these distances compare?

III. Set the gas jets at a distance from the lens equal to about five times its principal focal length, and place the screen so as to form as distinct images as possible of the jets.

Measure the distances: (1) From the lens to the screen; (2) from the lens to the gas jets; (3) between the gas jets; (4) between their images. Find a relation existing between these quantities and express it in the form of a proportion.

Reduce to decimals the reciprocal (1) of the principal focal length; (2) of the distance of either gas jet from the lens; (3) of its image from the lens. The sum of what two of these reciprocals is approximately equal to the third?

IV. Interchange the position of the gas jets and the screen and adjust the lens, if necessary, so as to make the images as distinct as possible. Repeat the measurements of III.

Form a proportion, if you can, similar to that formed in III, and find, if you can, a similar equation connecting certain reciprocals. Indicate any difference in the two cases.

V. Set an upright rod between the lens and the principal focus. On which side of the lens is the image of the rod? Is the image

real, or virtual; erect, or inverted? Locate this image by means of another upright rod, by the method of parallax, (Exercise 23, II.) In order that the relation between the reciprocals previously found should still hold true, what change in sign is necessary?

VI. Answer the following questions as applied to a convex or converging lens:—

1. Where should an object be placed in order that its image may be real? In order that its image may be virtual?

2. When will the image be erect, and when inverted?

3 Where should the object be placed in order to form an enlarged image? In order to form a diminished image?

4. Where should the object be placed in order to use a converging lens as a magnifying glass?

25. CONCAVE LENSES.

I Locate with an upright rod the image formed by a concave lens of some vertical part of the window-sash, using the method of parallax. (Exercise 23, part II.) (The rod used in locating the image should be looked at *over*, not *through*, the lens.) Measure the distance from the lens to the image.

Locate in the same way the image of some vertical object in the distance, as the corner of a house, or a telegraph pole, and find the principal focal length of the lens. Explain.

II. (*a.*) Place the vertical rod at a distance from the lens equal to about twice its principal focal length, and locate its image by means of another vertical rod. Measure the distance from the lens to the image.

(*b.*) Repeat with the stationary rod at the principal focus.

(*c.*) Repeat with the stationary rod between the principal focus and the lens.

Reduce to decimals the reciprocal: (1) of the distance from the lens to the image in either (*a*), (*b*), or (*c*); (2) of the corresponding distance from the lens to the object; (3) of the principal focal length. Which one of these distances should be made

negative in order that the sum of the first two reciprocals should be equal to the third?

III. Set two vertical rods attached to the same support at a suitable distance from the lens (to be determined by the student), and locate their images by means of two other separate rods.

Measure (1) the distance of the fixed pair of rods from the lens, (2) the distance of their images from the lens, (3) the distance between the rods, and (4) the distance between their images. Find the relation existing between these four quantities and express it in the form of a proportion, and state it in words.

IV. Answer the following questions:—

1. Can a real image be formed by a concave lens?

2. Can a concave lens be used as a magnifying glass?

3. Suppose an object at an infinite distance from a concave lens; where would its image be located, and how would it change in position as the object approached the lens, supposing the object to approach until it touched the lens?

4. Can there be, when a single lens or mirror is used, such a thing as a real and erect image, or a virtual and inverted image?

V. * When Exercises 23–25 have been done, copy and fill out the following table.

VI. Also construct geometrically the following:—

(1.) The image of an object within the focus of a concave mirror.

(2.) The image of an object at the center of curvature of a diverging lens.

(3.) The image of an object between the focus and center of curvature of a converging lens.

Demonstrate that to produce a real image with a converging lens the object and image must be separated by a distance of at least 4 f.

VII. Write what you can of the analogies between a concave mirror and a converging lens, between a convex mirror and a diverging lens.

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* Parts V and VI and VII may be handed in as a separate exercise.

		Concave Mirror.	Convex Lens.	Concave Lens.
$D = \infty$	Location of Image..	....	....	....
	Real or virtual	....	....	....
	Magnified or diminished......	....	....	....
$\infty > D > 2f$	Location of Image........	....	....	....
	Real or virtual	....	....	....
	Magnified or diminished	....	....	....
$D = 2f$	Location of Image	....	....	....
	Real or virtual....................	....	....	....
	Magnified or diminished	....	....	....
$2f > D > f$	Location of Image	....	....	....
	Real or virtual	....	....	....
	Magnified or diminished......	....	....	....
$f > D > o$	Location of Image	....	.. ..	....
	Real or virtual	... .	....	....
	Magnified or diminished	....	....	....

D=Distance of object from mirror.
f=Principal focal length.

26. DRAWING SPECTRA.

The spectroscope should be examined and its construction understood before proceeding. The instrument should be set so that the slit in the collimator does not point toward any outside source of light, as a window. The instrument may be adjusted for use as follows: Place a colorless Bunsen flame, in which is held asbestos soaked with salt solution, directly before the slit and narrow the latter, focusing upon it with the telescope, the prism being in place, until the slit appears as a sharp, bright line. Light the gas illuminating the scale in the third arm of the instrument, and focus the scale by moving it in and out until the figures upon it can be distinctly read. (The eye-piece should not be touched during this last operation.) Bring the 5 (or 50) mark of the scale into coincidence with the yellow line due to the sodium. If now the adjustment has been carefully done, by moving the eye slightly back and forth before the eye-piece the sodium line and the mark 5 will not appear to move with respect to each other. If there is such motion repeat the adjustment.

I. The spectra of the salts provided are to be examined and drawn upon plotting paper, the spectroscope scale being plotted as abscissæ and each spectrum on a separate horizontal line. (See sample note-book.) State in each case the general color of the flame and the colors of the various lines and bands.

To observe successfully the potassium spectrum it will be necessary to open the slit somewhat and insert a piece of cobalt glass between the flame and the slit. The sodium spectrum will probably be ever present, but is readily distinguished from that of the salt under examination.

II. Draw the spectrum of a luminous flame, and also of the same flame seen through red, green, yellow, and blue glass. Is the light transmitted by any of these glasses monochromatic?

Distinguish between absorption spectra and emission spectra.

III. The wave-lengths corresponding to certain spectral lines are furnished; draw a smooth curve in terms of their position on

the scale and from this curve determine the wave-lengths corresponding to the calcium lines and the strontium lines.

IV. Draw a diagram representing the optical principles involved in the construction and use of the spectroscope you used.

V. Write not less than one hundred words on the uses of the spectroscope.

27. LAWS OF MAGNETIC ACTION.

Prove that if a compass-needle is deflected by a horizontal force acting in an east and west direction, the magnitude of the force will be proportional to the tangent of the angle of deflection.

I. Place two pocket compasses side by side. Do the like poles attract or repel each other? Do the unlike?

II. Lay a compass on a large sheet of brown paper, draw a circle around it, and mark on the paper the center of the circle, *i. e.*, the position of the center of the compass. Draw a line east and west through this point and mark off on this line points in both directions at distances of 10, 15, 20, 30, and 40 cm., respectively, from the center of the compass. Remove all magnetic substances from the neighborhood, replace the compass, and adjust it so that its needle reads zero degrees. (The compass should be tapped very lightly as the needle comes to rest, with the finger or with a rubber pencil-tip.)

Hold a long magnetized steel strip in a vertical position with its lower end on the table at 10 cm. either east or west of the compass, and read the deflection of the compass-needle. (Tap the compass as before, and read both ends of the needle, averaging the readings.) Repeat with the end of the long magnet at 10 cm. on the other side and average the two deflections of the compass-needle, recording each observation. To what function of the angle of deflection is the force exerted by the lower pole of the long magnet proportional, assuming that the needle is comparatively short? (See proposition above.)

III. Repeat the last part of II with the end of the long magnet

at 15, 20, 30, and 40 cm., respectively, from the center of the compass, changing sides and averaging as before. Calculate from your results (using a table of natural tangents) the ratio of the horizontal force due to the lower pole of the magnet at 10 cm. to that at 20 cm.; at 15 cm. to that at 30 cm.; at 20 cm. to that at 40 cm.; etc. Does the force vary directly, or inversely, with the distance? Assuming that it varies (directly or inversely) as some integral power of the distance, what do you find to be the power in question? Arrange results in tabular form.

IV. Take a comparatively short magnet and lay it on the table on a line drawn east and west through the center of a compass-needle, at such a distance as to deflect the needle about 40°. Read the deflection and measure the distance from the center of the magnet to that of the compass-needle. Place the magnet at double this distance, and read the deflection again. Do you find the horizontal force to vary with the distance in this case according to the law found in III, or not? Was the needle in II and III acted on in a horizontal direction by both poles of the magnet, or practically by one alone? Was it in IV?

When a magnet is comparatively short, how do you find the force exerted by it at any point to vary with the distance of the point from the center of the magnet, assuming that it varies as some exact integral power of this distance?

V. A *unit magnetic pole* is a magnetic pole of such strength that it will exert a force of one dyne on a similar pole at the distance of one cm.

The *pole strength* of a magnetic pole is defined as the force exerted by it on a unit magnetic pole at the distance of one cm.

What is the force between two magnetic poles at the distance d apart, the strength of the poles being m_1, and m_2, respectively?

VI. If in IV the magnet were in the E and W line and the compass on a line perpendicular to the middle point of the magnet, in the same horizontal plane, find geometrically the expression for the force between a compass pole and the magnet.

28. MAGNETIC FIELDS.

I. Take a magnet 16.5 cm. long, and locate approximately the mean distance of either pole from the end, by the following method:—

Lay the magnet on a sheet of paper, and trace its outline with a pencil. Place a compass on the paper so that the compass box is about one cm. from the magnet. Commencing near the end of the magnet, move the compass, one or two cm. at a time, parallel to the magnet, drawing, for each position of the compass, lines to indicate the direction of its needle. Remove the magnet, draw a line through the position of its axis, and extend the above lines until they intersect this line. Find a medium point and measure its distance from the end of the magnet.

II. Lay the magnet used in I lengthwise on a large sheet of brown paper. Draw the outline of the magnet with a pencil, and sprinkle iron filings on the paper around it. Trace the lines in which the iron filings set themselves when the paper is tapped.

Brush the iron filings off the magnet, and return them to the sprinkler, taking care not to scatter and waste them. (In removing iron filings from a magnet, brush them towards the center, and not towards the ends.)

Replace the magnet, and place a small compass at different points of the tracing. How does the direction of the compass-needle at any point coincide with that of the lines of iron filings?

III. Take a sheet of cardboard and place it with its sides parallel to the edges of the table. To the most northerly or southerly corner of the cardboard fasten a small compass with wax*, and, after removing all magnetic substances from the neighborhood, draw a pencil line to correspond with the magnetic meridian through the compass. On this line place

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*Attach the wax to the edge of the compass, and do not put it underneath.

a short magnet with its north pole directed toward the south, and adjust the distance between it and the compass so that the compass-needle is in neutral equilibrium (*i. e.*, will point indifferently in any direction). Fasten the magnet in this position to the cardboard with wax. The compass-needle will not be affected now by the earth's magnetic field, while the sides of the cardboard are parallel to the edges of the table. Why?

IV. Take the drawing made in II. Mark the position of the poles of the magnet, and draw a circle, about 2 or 3 cm. in diameter, around each. Divide these circles into 12 or more equal parts, and through each division draw a line, following the directions in which the iron filings set themselves, as far as these directions can be determined.

Replace the magnet on the paper, and place the compass-needle, protected as in III from the influence of the earth's magnetic field, at the end of one of these lines. Extend this line an inch or so in the direction indicated by the needle. Prolong all the lines through the divisions of the circle in this way, an inch or so at a time, as far as the limits of the paper will allow.

V. Take a point on one of these lines about 9 or 10 cm. from one of the poles of the magnet, and 12 or 15 cm. from the other pole. Suppose a north or south magnetic pole to be placed at this point. Draw lines in the directions that this pole would be urged by each pole of the magnet, and lay off on these lines distances proportional to the forces in these directions due to the poles taken separately. (Force varies inversely as the square of the distance.) Construct on these lines a parallelogram of forces, and find the direction of the resultant force due to both poles of the magnet. How does the direction of this resultant compare with that of the magnetic line of force at point considered?

If it were possible to produce an isolated north magnetic pole and place it in a magnetic field, how would the path along which it would move be related to the magnetic lines of force? Deduce

from this a definition of a *magnetic line of force*. How is the strength of the magnetic field due to the magnet indicated by the distribution of the lines of force at any region in the preceding diagram?

The sheet of brown paper used in II, IV, and V is to be signed and handed in with the other notes. Each student, however, should make in his note-book a reduced copy of the diagram before handing it in.

VI. Lay two short magnets on a sheet of white paper with impression paper and another sheet of white paper underneath (or they may be laid directly on a page of the note-book). Lay them parallel, side by side, about 1.5 or 2 cm. apart, with their unlike poles opposite. Sprinkle iron filings about them, and trace the lines along which the filings set themselves.

29. INTENSITY OF EARTH'S MAGNETIC FIELD. I.

Caution.—Keep the magnet used in this exercise away from other magnets or magnetic bodies.

I. (*a.*) Place a magnet in the east and west line east or west of a compass-needle, at such a distance as to deflect the needle through an angle of 45°. Measure the length of the magnet and the distance of its nearer end from the center of the compass.

(*b.*) Reverse the magnet and repeat the measurements of (*a*).

(*c.*) Repeat (*a*) and (*b*) with the magnet on the other side of the compass-needle.

II. (*a.*) Suspend a carriage for the magnet by two fine parallel wires of equal length, adjustable from above, so that they are east and west of each other. Place a brass rod of about the same size as the magnet in the carriage and carefully draw a line parallel to the rod on a piece of paper placed underneath it. Remove the brass rod and place the magnet in the carriage. Does the magnet lie, as the rod did, east and west, or not? Explain why. Mark on the paper the position of the magnet.

(*b.*) Reverse the magnet and mark its position again.

(*c.*) Measure the distance between the two wires of the bifilar suspension, and mark their position carefully on the paper in the three cases above. Find, by measurement from the drawing, the average distance that the lower end of either wire is pulled out from the vertical when the magnet is hung in its carriage.

What forces cause the magnet to be deflected? What is the direction of these forces, and where do they act on the magnet, assuming that the poles of the magnet are at its extremities? Measure on the paper the arm of the couple (see Exercise 11, VI) formed by these forces.

Measure the length of the bifilar suspension and also find the weight of the magnet and carriage. Express these weights in dynes.

Repeat Part II, using another part of the same paper. Average the two sets of results.

Preserve the paper diagram for reference.

30. INTENSITY OF EARTH'S MAGNETIC FIELD. II.

This exercise need not be performed in the laboratory, and is to be done only when the other exercises on magnetism have been performed.

I. In Exercise 29, I, how did the horizontal force at the center of the compass due to the magnet compare in each case with that due to the earth's magnetic field?

Calculate the average force on a unit magnetic pole at the center of the compass due to the nearer pole of the magnet, calling the pole-strength of the magnet P (see Exercise 27, V) and assuming that its poles are situated at its extremities. Do the same for the farther pole of the magnet. How did these forces compare in direction? Find their resultant. How does this resultant compare with the horizontal force (usually denoted by the letter H) on a unit magnetic pole due to the earth's field? (See question above.)

Form an equation from these results and find from it the numerical value of the quotient H/P.

II. Assuming that the weight in Exercise 29, II, was evenly divided between the two wires of the bifilar suspension, calculate the horizontal force on the lower end of each wire tending to pull it back into a vertical position. Do this by means of a triangle of forces as in Exercise 12, VI, using the length of the wire and the deflection from the vertical, as measured in Exercise 29. In what direction did these forces act, and what was the arm of the couple (see Exercise 11, VI) formed by them? Calculate the moment of the couple formed by these forces. Draw diagrams of forces.

What two forces tended to deflect the magnet? To what was each of these forces equal in terms of H and P? Calculate the moment of the couple formed by these forces.

What relation exists between the moments of the two couples just calculated? Express this relationship in the form of an equation, and calculate the numerical value of the product $H \times P$.

III. Combine the results found in I and II so as to eliminate the unknown quantity P and find the value of H in dynes. Calculate also the pole-strength; in what unit is it expressed?

IV. Write not less than two hundred words on the subject: Terrestrial Magnetism.

31. COMPARISON OF MAGNETIC FIELDS.

I. Suspend a magnet in a horizontal position by a long thread (a torsionless thread, if possible), and protect it from air currents by hanging it in a box. When the suspended magnet has been brought to rest, set it vibrating about a vertical axis by bringing an open knife blade near it, and determine its period of vibration within a few hundredths of a second.* Be careful not to touch the magnet with magnetic substances, and also keep all movable magnetic bodies away from the neighborhood of the vibrating magnet.

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*Find the period by the method of Exercise 15.

II. Mark in some way the position of one end of the magnet, remove it, and place a compass with a short needle at this point. Place a long magnet at right angles to a line drawn east and west through the thread with its center on this line and its south pole towards the south. Move this magnet parallel to itself until the earth's horizontal field at the center of the compass is as nearly neutralized as possible. Then turn the magnet through 180°, *i. e.*, end for end. Will the intensity of the horizontal magnetic field at the compass-needle now be greater or less than the earth's horizontal field, H? How much greater or less?

Remove the compass, replace the suspended magnet, and determine its period of vibration again as in I. Calculate the ratio of the periods in the two cases. How does this compare with the intensity of the horizontal magnetic fields in the two cases?

Assuming that the period of a vibrating magnet varies as some integral root, or power, of the intensity of the magnetic field parallel to the magnet, what do your results indicate this root, or power, to be? Is it direct or inverse?

III. Suspend your magnet at two designated places in the aboratory, determining its period of vibration at each place and also at a place where H is known. From your results and the law just found, calculate the value of H at each of the places where the magnet was vibrated.

IV. If the suspending string were not torsionless, would the calculated values of H be too high or too low? Explain.

What analogies exist between this magnetic pendulum and the simple gravity pendulum?

32. ELECTRO-MAGNETIC RELATIONS.

I. Connect the plates of a Daniell cell by a flexible wire cord. Stretch a portion of this cord out straight and hold it near a compass-needle placed on the edge of a wooden block. The electric current is supposed to flow through the external circuit

from the copper plate of the cell to the zinc plate. In what direction is the north pole of the compass-needle deflected, or is it deflected at all, when the current and the needle are in the following relative positions:—

1. Current flowing north, needle below?
2. Current flowing north, needle above?
3. Current flowing north, needle east or west?
4. Current flowing south, needle below?
5. Current flowing south, needle above?
6. Current flowing south, needle east or west?
7. Current flowing upward, needle north?
8. Current flowing upward, needle south?
9. Current flowing downward, needle north?
10. Current flowing downward, needle south?
11. Current flowing east or west, needle above or below?
12. Current flowing east or west, needle north or south?

II. Answer the following questions:—

1. How is the direction in which the compass-needle is deflected affected by reversing the direction of the current?

2. How is it affected when its position is changed from one side of the current to the other, *i. e.*, from above to below and from east to west?

3. Is the force exerted by an electric current on a magnetic pole parallel to the direction of the current or not? What do the results of I, 1 and 2, indicate?

4. What is the direction of this force, with reference to the plane containing the current and the magnetic pole, as indicated by the results of I, 3 and 6?

5. If the needle was not deflected in I, 11, explain why.

6. Suppose the current is represented in position and direction by the fingers of the right hand and the palm to be turned towards the compass-needle, which pole was deflected in the direction indicated by the thumb in I, 1; in I, 2; in I, 3, etc.? Frame a rule including all the above cases.

III. Connect the plates of the Daniell cell to a rectangular coil suspended with its terminals in mercury cups so as to turn freely about a vertical axis. Set the coil with its plane north and south. Follow the path of the electric current from the copper plate of the cell through the coil to the zinc plate, and find in what part of the coil the current flows in a northerly direction, in what in a southerly direction, in what part upward, and in what part downward.

Take a magnet and hold its north pole in the following positions relative to the current, observing in each case the direction in which the wire carrying the current tends to move:—

1. Current flowing north, north pole below.
2. Current flowing north, north pole above.
3. Current flowing south, north pole below.
4. Current flowing south, north pole above.
5. Current flowing upward, north pole north.
6. Current flowing upward, north pole south.
7. Current flowing downward, north pole north.
8. Current flowing downward, north pole south.

How does the force exerted by a magnetic pole upon an electric current compare in direction with that exerted by the current upon the pole? (Compare the results of I and III.)

IV. Trace by means of iron filings the magnetic field due to a helical coil carrying a current. To the field of what shape magnet does this resemble?

Test the coil with a compass-needle and determine which end attracts the north pole and which the south pole of the needle. Could the position of its poles be determined beforehand? How?

V. What do you conclude from I, II, and III to be the form of the magnetic field about a wire carrying a current?

How does an electric circuit tend to set itself with respect to the number and direction of the magnetic lines of force in its neighborhood? (A magnetic line of force proceeds from the north pole to the south pole outside the magnet.)

Does the coil used in III act as if it were itself a magnet? If so, of what form?

33. LAWS OF ELECTRO-MAGNETIC ACTION.

I. Take an upright wooden circle about 30 cm. in diameter, having a piece of insulated copper wire wound once around it, with two free ends of about equal length twisted together so that the effect of an electric current in one will be neutralized by that of an equal and opposite current in the other. Place a compass-needle at the center of the coil, and set the coil so that its plane is parallel to the magnetic meridian.

Connect this galvanometer with some source furnishing a constant electric current. Read the angle of deflection of the compass-needle. Reverse the direction of the current and read the angle again. Average the two results.

In what direction is the force tending to deflect the needle? (See Exercise 32.) To what function of the angle of deflection is this force proportional? (See Exercise 27, Proposition.)

II. Repeat I with a coil of the same diameter, but having twice the length of wire as in I, *i. e.*, having twice as many turns of wire.

III. Take another wire and wind it once around a wooden circle concentric with and of half the diameter of that used in I. Connect these two coils so that the same current will flow through them in opposite directions. Increase the number of turns of the larger coil until the effect of the smaller coil on the compass-needle is neutralized. How many turns of wire were necessary to do this? How many times did the length of the wire have to be increased from that of the single turn on the inner coil in order to neutralize the effect due to the decrease in the diameter of the coil?

IV. Set up three such galvanometers having coils of the same diameter and length, placing them as far apart as the table will allow, and connect them so that the whole current passes through

one coil and half of the current through each of the other coils. Read the angle of deflection of each compass-needle. Reverse the direction of the current and average the east and west deflections of each galvanometer.

V. Answer the following questions, showing in each case the numerical process by which you arrived at your conclusion:—

1. How does the force at the center of a circular coil carrying an electric current vary with the length of wire in the coil, according to the results of I and II, assuming that it varies with some integral power (direct or inverse) of the length?

2. How with the diameter or radius of the coil, according to the results of II and III?

3. How with the current, according to the results of IV?

Assuming that the force F on a unit magnetic pole at the center of a circular coil depends only on the length, $L=2\pi RN$, of wire in the coil, its radius, R, and the current, C, express this force in terms of these three quantities and a constant K.

VI. Draw diagrams of all electrical connections.

Represent graphically the magnetic field at the needle when the latter is deflected 45°.

GROUP IV.

In all the electrical experiments, diagrams of electrical connections are to be made.

Instruments of the tangent galvanometer type—a loop of wire about a magnetized needle—should be set with the plane of the coil in the magnetic meridian and leveled so that the needle swings freely. Wires leading to such an instrument, or near it, should be twisted or laid side by side so that the magnetic fields of currents in opposite directions neutralize each other. Two instruments should never be nearer each other than one metre.

To take an observation, read both ends of the pointer, reverse the direction of the current, read both ends of the pointer again, and average the four readings. Reading both ends of the

pointer eliminates eccentricity of mounting of the needle with respect to the scale. Reversing the current corrects for the imperfect orientation of the coil in the magnetic meridian. Note that the pointer is usually mounted at right angles to the needle. In the case of needles mounted on pivots *slight* tapping of the instrument may be necessary to insure a correct reading. The influence of one instrument upon another may be tested by reversing the current through one of them.

It is important in all electrical work that the connections be tight. Always disconnect from batteries when through.

In all cases the above methods are to be used and the indicated precautions taken.

34. CURRENT DETERMINATION.

I. Connect a tangent galvanometer, such as was used in Exercise 33, in series with an ammeter and a source of constant current, following the preceding directions for setting up and reading. Take five sets of readings on different parts of the scale of both instruments simultaneously, varying the current by introducing into the circuit various lengths of German silver wire. Record *all* readings and take the proper averages.

II. From the laws of electro-magnetic action studied in Exercise 33 we may calculate the value of the current for the various readings of the galvanometer, and comparing these values with the ammeter readings, both expressed in the same unit, we may calibrate or test the ammeter.

The C. G. S. unit of current in the electro-magnetic system is the current that will act with a force of one dyne on a unit magnetic pole at the center of an arc 1 cm. long of 1 cm. radius. If C in the equation of Exercise 33, V, was measured in terms of this unit, F in dynes, and R and L in cm., the constant K may be eliminated. How? Solve the resulting equation for C.

Also $F = H \tan \theta$ where H is the horizontal component of the earth's magnetic field and θ the angle of deflection of the needle.

Now F is the same quantity in the above two equations. The two values of F may therefore be equated and an expression for the current through the galvanometer found in C. G. S. units in terms of the four measurable quantities: the radius R of the coil, the length $L = 2\pi RN$ of wire in the coil (where N is the number of turns), the horizontal component H of the earth's field, and the tangent of the angle of deflection θ. (The value of H will be given.)

III. Measure the radius of the galvanometer coil and find its length. Calculate the values of the current, in C. G. S. units, for the readings of the galvanometer taken in I.

How do the calculated values agree with the ammeter readings of the current? What, then, is the ratio between the C. G. S. unit of current and the ampere—the practical unit indicated by the ammeter?

IV. Make a table of corrections to the readings of the ammeter in terms of the current as calculated.

V. Explain what reversing the current in a tangent galvanometer eliminates?

35. ELECTRICAL RESISTANCE.

I. (*a.*) Connect an ammeter directly with the battery terminals and read the current. Disconnect as soon as possible.

(*b.*) Introduce 50 cm. of No. 25 German silver wire into the circuit in series with the ammeter. Read the current. How was its value altered, by introducing this wire into the circuit?

(*c.*) Repeat with 100 cm. of No. 25 German silver wire, at the same time introducing into the circuit a wire equal in size and length to the wires leading to the battery. What is the effect on the current of doubling the length of the wire in the circuit?

If we consider that the wire offers *resistance* to an electric current, and assume that the resistance varies as some integral power of its length, what do the results of (*b*) and (*c*) show this power to be? Is it direct, or inverse?

II. (*a.*) Repeat I (*c*) with two No. 25 German silver wires, each 100 cm. long, connected in parallel, instead of the single wire. What is the effect upon the current of paralleling the resistance wire with another wire of the same material and of equal diameter and length?

(*b.*) Remove the extra wire inserted in the circuit in 1 (*c*), and adjust the length of the two wires, so that the current through the ammeter is the same as in I (*b*). How does the resistance of the two wires in parallel, after this adjustment, compare with the resistance of the single wire in I (*b*)? How do their lengths compare? What do you find to be the ratio of the resistance of a single wire to that of two wires of the same material, length, and diameter connected in parallel?

III. (*a.*) Connect a No. 25 German silver wire 20 cm. long in series with the ammeter and read the current.

(*b.*) Replace the No. 25 German silver wire by a No. 20 German silver wire of the same length, and measure the current again. What do you find to be the effect of increasing the cross-section of a wire upon the current?

(*c.*) Adjust the length of the No. 20 German silver wire so that the current through the ammeter is the same as in III (*a*). How does the length of the No. 20 wire compare with that of a No. 25 wire having the same electrical resistance?

(*d.*) With a screw gauge meaure the diameter of the No. 25 and also of the No. 20 wire. What is the ratio of the diameters of the two wires? What is the ratio of the resistance of a No. 25 wire to that of the same length of No. 20 wire? Explain. Assuming that the electrical resistance varies as some integral power of the diameter of a wire, what do you find the power in question to be? Is it direct, or inverse? How must the resistance vary, then, with the cross-section of the wire? How do the results of II (*b*) confirm your answer to this last question?

IV. (*a.*) Introduce 50 cm. of No. 25 nickel wire into the circuit, instead of the German silver wire, and measure the current.

What is the ratio of the resistance of the German silver and nickel wires of the same length and diameter?

(*b.*) Replace the brass wire by the No. 20 German silver wire and adjust its length so that the current through the ammeter is the same as in IV (*a*).

Having found a certain length of No. 20 German silver wire equal in resistance to 50 cm. of No. 25 nickel wire, and knowing the diameters of these wires, calculate the relative resistance of nickel and German silver wires of the same diameter and length.

V. The resistance of a cubic centimeter is called the specific resistance of a substance. If the specific resistance of German silver is known, show how that for nickel may be calculated from your results. Write the equation representing this.

36. ELECTROMOTIVE FORCE.

I. (*a.*) Connect a low-resistance galvanometer (an ammeter) directly to a Daniell cell and note the reading. Introduce another Daniell cell into the circuit in series with the first cell, connecting the copper plate of one cell to the zinc plate of the other, so that the currents due to both flow in the same direction through the ammeter. What change did the second cell produce in the reading of the ammeter, if any?

(*b.*) Repeat (*a*) with a high-resistance galvanometer, constructed so that the effect on the deflection due to diminishing the current is offset by having a great number of turns in the coil. How did the change in the reading produced by introducing an additional cell into the circuit compare with that produced by the additional cell when an ammeter was used? Should a galvanometer of high or low resistance be used to show the effect of connecting two battery cells in series?

The effect of connecting two cells in series is to double the *electromotive force** tending to produce an electric current in

*The practical unit of electromotive force is called a volt, and a high-resistance galvanometer graduated to give the electromotive force

the circuit. What sort of a galvanometer (high or low resistance) do your results indicate should be used to measure the electromotive force due to any source of electric currents, or between two points of a circuit carrying a current? What is the objection to using a high-resistance galvanometer to measure the *current* in a circuit?

II. With a voltmeter measure the electromotive force of the following cells and combinations of cells, and answer the questions asked. (The directions for using a galvanometer apply also to a voltmeter.)

1. A Daniell cell.
2. Two Daniell cells in series, connected copper to zinc.
3. Two Daniell cells in series, connected copper to copper.
4. Two Daniell cells in parallel.

Are the electromotive forces of the individual Daniell cells equal? (Compare 1, 2, and 3.) How does the electromotive force of two Daniell cells in parallel compare with that of a single cell? With that of two cells in series? (Compare 1, 2, and 4.)

5. A Leclanché cell. (Zinc and carbon plates in a solution of sal ammoniac,—ammonium chloride.)

6. A Leclanché and a Daniell cell in series, connected carbon to zinc and copper to zinc.

7. The same cells in series, connected carbon to copper and zinc to zinc.

Is the electromotive force of a battery cell altered in any way when it is connected to another cell of different construction? (Compare 1, 5, 6, and 7.)

8. Any other cells or sources of electromotive force provided.

III. Measure the electromotive force of a Daniell cell, and of a Leclanché cell, after being short-circuited for fifteen or twenty minutes. Was the electromotive force of the Daniell cell the

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between its terminals in volts is called a voltmeter. The instruments of this class used in (*b*) were designed for use as voltmeters and will be designated as such hereafter. The electromotive force of a Daniell cell is 1.07 volt.

same as that found in II? Was that of Leclanché the same? If not, why? Which cell do you conclude is unsuitable for use where a constant current is required, as in telegraphing? Give a reason why the other cell would be unsuitable for use where the circuit would only be closed for a moment at a time and at long intervals, as on a bell circuit. Disconnect all wires from cells. Is electromotive force a force? Explain.

37. OHM'S LAW.

I. (*a.*) Connect a single Daniell cell in series with a rheostat and an ammeter. Take out enough plugs from the rheostat to introduce a resistance of 5 ohms* into the circuit. Read the ammeter carefully, reversing as usual. (Do not be surprised if the current is small.)

(*b.*) Introduce another Daniell cell into the circuit in series with the first cell. Read the ammeter again.

(The electromotive force in (*b*) is twice that in (*a*). (See Exercise 36, II.) What relation do you find to exist between the electromotive force and the current when the resistance is constant?

II. (*a.*) With the connections as in I (*b*) take out enough plugs from the rheostat to increase the introduced resistance to 7 ohms. Read the ammeter.

(*b.*) Repeat II (*a*) with all the rheostat plugs out. (Resistance=10 ohms.)

How do the currents through the ammeter in I (*b*), II (*a*), and II (*b*), compare? How do the resistances of the circuits compare, neglecting the comparatively small resistance of the battery cells? What relation do you find to exist between the resistance and the current when the electromotive force is constant?

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*The ohm is equal to the resistance at 0° C. of a column of mercury 106.3 cm. long and 1 sq. mm. in cross section.

What, from the results of I and II, is the relation between the current in a circuit (or part of a circuit), the electromotive force acting through the circuit (or between its terminals, if it is not a complete circuit), and the resistance of the circuit (or part of a circuit)? This relation, when written correctly in the form of an equation (assuming the units of current, electromotive force, and resistance to be so related that the constant factor is unity), is called *Ohm's Law*.

III. Connect the ammeter in series with a rheostat and two Daniell cells in parallel. Vary the resistance by steps of one ohm over the range of the rheostat. Read the corresponding currents. Make a plot with values of resistance as abscissæ and products of current by resistance as ordinates. Also plot resistances and currents on the same paper. Explain by Ohm's law the forms of the lines drawn.

Show how the resistance varies with the electromotive force when the current is constant.

38. DIVIDED CIRCUITS AND FALL OF POTENTIAL ALONG A CONDUCTOR.

I. (*a.*) Join two rheostats in parallel and connect them in series with the battery provided and an ammeter. Cut out the resistances in the rheostats, leaving but one ohm in one branch of the circuit, and two ohms in the other. Read the current through the ammeter.

(*b.*) Place the ammeter in the branch circuit of one ohm's resistance, and measure the current in this branch.

(*c.*) Measure in the same way the current in the branch circuit of two ohms' resistance.

(*d.*) Answer the following questions:—

1. How does the current in the main circuit compare with the sum of the currents in the two branch circuits?

2. Does the greater current flow through the circuit of greater or less resistance?

3. The currents in a divided circuit are proportional to an integral power of the resistances of the branches. What do your results indicate this power to be? Is it direct, or inverse?

II. Connect the two rheostats with a third so as to form three parallel circuits of one, two, and three ohms' resistance, respectively. Measure with an ammeter, as was done in I, the current in the main circuit and in each of the branch circuits. Measure with a voltmeter the electromotive force between the two junctions of the parallel circuits.

Is the relation found in I between the currents in the branch circuits and the resistances of the circuits confirmed by the results of II? Explain.

III. Connect an external resistance of 10 ohms having steps of 2 ohms, in series with the battery.

Connect one of the voltmeter terminals to one plate of the battery and the other terminal to points on the rheostat separated from this plate by resistances of 2, 4, 6, 8, 10 ohms, respectively. Plot resistances as abscissæ and voltmeter readings as ordinates. What does the plot indicate to be the relation between the fall of potential along a conductor and the corresponding resistances? Is the fall of potential over 2 ohms' resistance the same in all parts of the circuit?

IV. Calculate from the readings of the ammeter and voltmeter, by means of Ohm's law,* the combined resistance of the three circuits in II when joined in parallel.

What relation exists between this resistance and the resistances of the separate branches?

The reciprocal of the resistance of a conductor of electricity is called its *conductivity*. Calculate the conductivity of each of the parallel circuits in II separately, and also the conductivity of the three in parallel. What relation exists between the conductivity of the whole, and the sum of the conductivities of the separate branches, of the circuit?

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*For statement of Ohm's law, see text-book or Exercise 37.

V. Deduce algebraically from Ohm's law the relations found experimentally in I and II, finding the equations for the resistance of circuits of two and of three branches in parallel.

39. ARRANGEMENT OF BATTERY CELLS; THEIR ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE.

I. Connect three Daniell cells in series with each other (zinc to copper) and in series with an ammeter and a rheostat. Also connect a voltmeter to the terminals of the battery. Read the voltmeter and ammeter simultaneously, varying the external resistance from o by steps to the limit of the rheostat. Disconnect the ammeter and rheostat and read the voltmeter.

II. Repeat I with the three cells in parallel (coppers together and zincs together).

III. What from I and from II is the value of the electromotive force of a single Daniell cell? Measure this quantity directly with the voltmeter. Also read the ammeter connected to a single Daniell cell.

By Ohm's Law find the internal resistance of a single Daniell cell, of three in parallel and of three in series. What are the corresponding electromotive forces?

IV. Construct a plot, from the results of II, with external resistances (R) as abscissæ and *terminal potential differences* ($E'=CR$ where $C=$current) as ordinates. The electromotive force E of the battery is given by the voltmeter reading on open circuit. Indicate this quantity on the plot also. For what resistance in the external circuit does the terminal potential difference become zero? On what does the terminal potential difference depend? Deduce an equation (based on Ohm's law) giving the relation between the electromotive force of a battery in terms of the internal and external resistances and the current. Modify this to include the terminal potential difference.

V. In I and II, which arrangement of cells gave the greatest current when there was no external resistance in the circuit? Which when the highest resistance used was introduced? Explain why in each case.

In general, how should a number of cells be connected in order to obtain the greatest possible current?

(1.) When the resistance in the external circuit is very small.

(2.) When comparatively large.

Explain these results algebraically by Ohm's law.

40. COMPARISON OF RESISTANCES BY WHEATSTONE'S BRIDGE.

I. Connect a Leclanché cell to the bridge-wire of a Wheatstone's bridge, and connect a sensitive galvanoscope, by one terminal, to the sliding contact. (As the galvanoscope is simply used to show the presence or absence of an electric current, the motion of its needle is restricted to a few degrees.) Connect also two rheostats in series with each other and in parallel with the bridge-wire, and join the free terminal of the galvanoscope to the junction of the two rheostats. A circuit of six branches is thus formed, with the galvanoscope in one branch, the battery cell in another, the rheostats in two branches, and two branches formed by portions of the bridge-wire.

With a resistance of five ohms in each rheostat set the sliding contact so that there is no current through the galvanoscope. Interchange the rheostats and repeat.

Measure the lengths of the two portions into which the bridge-wire is divided in each case. What is the mean ratio of these two lengths? How does this ratio compare with the ratio between the two resistances in the rheostats?

II. Repeat I, with resistances of 5 and 10 ohms, respectively, in the rheostats; with resistances of 7 and 10 ohms. What proportion do you find can always be formed between the resistances in the rheostat branches and the two lengths into which

the bridge-wire is divided when there is no current through the galvanoscope? Indicate clearly.

III. What must be the difference of potential between the two points where the galvanoscope is connected when there is no current indicated? Why? Show, by applying Ohm's law to the four branches formed by the two parts of the bridge-wire and the two resistances, that, when this is the case, the proportion found in II must hold true.

IV. Replace one of the rheostats by 100 cm. of No. 25 German silver wire. Adjust the sliding contact so that there is no current through the galvanoscope, and measure the lengths into which the bridge-wire is divided. Using the rheostat resistance as a standard, calculate, by means of the proportion found in II, the resistance of 100 cm. of No. 25 German silver wire.

V. Repeat IV with various coils of wire on the table, instead of the German silver wire, and find the respective resistances of these coils. Record the numbers on the coils.

VI. Repeat IV with a coil of fine copper wire immersed in cold water, and then in hot water, taking the temperature of the water in each case after stirring. From your results calculate: (1) The resistance of the coil at each temperature; (2) the change in resistance per degree rise in temperature; (3) the resistance at 0°; (4) the change in resistance per degree rise in temperature of each ohm at 0°. The last result will be the *temperature coefficient* of the electrical resistance of copper.

41. HEATING EFFECT OF AN ELECTRIC CURRENT.

I. Fill a small calorimeter, that has been weighed with its stirrer, two-thirds full of ice-cold water and weigh. Adjust in place the heating-coil provided having the higher resistance, and insert a thermometer in the water through the opening in the cover to which the coil is attached. Stir thoroughly, taking care not to splash the water and *keep stirring* throughout the exercise.

Connect the heating coil in series with an ammeter and with the terminals of the power circuit marked "large current," making the final connection at a noted minute and taking the temperature at the same instant. Read the temperature and the current each every minute on alternate half minutes, until the temperature is half as high above that of the room as it was below at the start.

II. Repeat I connecting to the terminals marked "small current."

III. Repeat I (with the same terminals as in I) using the coil of lower resistance.

IV. Calculate the heating effect of the current in each of the three cases, in degrees per second.

Show from the results of I and II to what power of the current the heating is proportional.

From the results of I and III show how the heating varies with the resistance when the current is constant.

V. What becomes of the energy expended in maintaining an electric current through a conductor?

Form an equation representing the relation of the heating to the current, resistance and time.

Calculate the heat imparted by the coil in I on the assumption that all goes to the water, calorimeter and stirrer. (The necessary specific heats are given.)

The energy expended electrically is given in joules when expressed in terms of the units: the ampere, ohm, and second. From the relation found above calculate in joules the energy expended in I, using the average value of the current. Deduce the ratio of the calorie to the joule. What is this quantity?

Calculate in watts the power required in I.

What is it now necessary to know to calculate the value of the watt in ergs per second? Explain.

VI. By means of Ohm's Law and the relation of V, find an expression for the heating effect in terms of the electromotive force and the current.

42. LAWS OF ELECTROLYSIS.

I. Scour with emery cloth the six plates of the three copper voltameters, then wash and dry them, taking care not to touch the polished surfaces and not lay them on anything other than clean white paper. Weigh these plates carefully on a sensitive Jolly balance, recording the numbers on the plates in order to identify them later. Place the plates in the dilute, slightly acid copper sulphate solution which fills each of the voltameters, two plates in each voltameter, adjusting so that the plates are parallel in each cell. Connect the voltameters so that the whole current will go through one of them and half through each of the other two, arranging so that the current will go from the thick to the thin plate in each cell. Diagram. State how you determine the direction of the current. The circuit is completed by connecting in series an ammeter and storage battery. The final connection completing the circuit is to be made at a noted instant of time. Leave the circuit closed for fifty minutes exactly and read the current every two minutes. At the close of the run wash, dry, and weigh the plates with the same precautions as before. Record on the diagram the gain or loss of each plate.

II. 1. Was the copper carried with or against the current? Which, then, are the gain plates, those by which the current enters or leaves the cells? How does the electrolytic cell compare in this respect with the voltaic cell?

2. In each voltameter how did the gain of mass in one plate compare with the loss of mass in the other?

3. What relation exists between the gain in mass of the gain plate in the voltameter through which the whole current passed and the corresponding quantities for the other two voltameters? Does the same relation hold for the loss plates?

Find how the mass of copper deposited varies with the current.

III. Using the average value of the current in I, calculate for each cell the mass of copper that would be deposited from a copper sulphate solution by a current of one ampere in one

second, and find the average. This quantity is known as the *electro-chemical equivalent* of copper.

IV. If zinc electrodes in a zinc sulphate solution were used, would you expect the same quantity of zinc to be deposited in the same time by the same current, as above?

Look this up and state the remaining law of electrolysis.

Express in the form of an equation the laws of electrolysis.

43. ELECTROMAGNETIC INDUCTION.

I. (*a*.) Connect a coil of wire to a sensitive galvanometer, after testing with a Leclanché cell what is the direction of the current corresponding to a deflection to the right and left. (Be careful not to disturb the galvanometer and accessory apparatus.) Connect an electro-magnet to the storage battery terminals.

Hold the coil in the field of the electromagnet perpendicular to the direction of the field, opposite the north pole of the magnet. Then turn the coil *quickly* through 90°, so that it becomes parallel to the direction of the field. Note the deflection of the galvanometer, and whether a clockwise or counter-clockwise current is induced in the coil, looking along the lines of force.

(*b*.) With the coil held as in (*a*) remove the electromagnet from before the coil, noting deflection and direction of induced current as before.

(*c*.) With the coil and magnet as in (*a*), break the circuit of the electromagnet. Record as before.

In (*a*), (*b*), and (*c*) how do the currents compare in magnitude and direction? Viewing the coil in the direction of the lines of force, was the number of lines through the coil diminished or increased in each case? Does then diminishing the number of lines of force through a closed circuit induce a clockwise or a counter-clockwise current in the circuit?

II. Repeat I (*a*) with the same coil but inserting a resistance in the circuit equal to the previous total resistance of the circuit. Compare the current induced with that in I. How did it vary

with the resistance in the circuit? Which do you conclude is the quantity that remained constant, the induced current or the induced electromotive force? Is it better then to speak of inducing an electromotive force or a current by moving a closed circuit in a magnetic field?

III. (*a.*) Remove the extra resistance, and rotate the coil from its final position in I through another 90°. Apply the rule deduced in III, for the direction of the induced current (electromotive force). Does it still hold true?

(*b.*) Rotate the coil through 180° more by steps of 90°. What is the effect of increasing the number of force-lines through the coil on the direction of the induced current (electromotive force)?

(*c.*) Repeat I (*b*) with the electromagnetic turned end for end. Is the result of III (*b*) confirmed?

IV. Repeat III (*b*) with a coil having twice as many turns of wire. How do you find the induction to vary with the number of turns of wire in the coil? If you consider each turn as enclosing a certain number of force-lines, how then does the induction vary with the total change in the number of the force-lines threading through the coil?

V. (*a.*) Hold the coil stationary, as in I (*c*), and remove the core only of the electromagnet. If the galvanometer is deflected, read the deflection. Replace the core and read the deflection, if any, again. Explain the effect in each case.

(*b.*) Remove the core very slowly and read the deflection of the galvanometer. Does this experiment indicate that the induced current (electromotive force) varies with the rate at which the change in the magnetic field is produced? How does the rate of change affect the induced electromotive force?

VI. The general laws of electromagnetic induction may be stated thus: When the magnetic field is altered in any way with respect to an electric conductor, an electromotive force is induced in the conductor. This induced electromotive force is proportional to the rate of change in the magnetic field, and its direc-

tion is such as to produce a current that will oppose the change in the field.

Show how the results obtained in I–V may be explained by means of this law.

44. EARTH INDUCTOR.

I. (*a.*) Set up a sensitive galvanometer and connect it with an earth-inductor, placing them as far apart as the table will allow. Place the earth-inductor so that the two stationary, upright supports are in an east and west line, and set the circle so that its axis of rotation is horizontal.

Turn the circle slowly into a horizontal position, let the galvanometer-needle come to rest, and then turn the circle suddenly through 180°, noting the effect on the galvanometer. Explain the cause of the current produced.

(*b.*) Turn the circle in the same direction through another 180°, and compare the induced current with that in I (*a*). Was its direction the same? What would its direction have been if there had been no commutator?

(*c.*) Rotate the coil continuously and uniformly, recording the number of turns per minute and the deflection of the galvanometer.

II. Set the coil so that its axis of rotation is approximately in the direction of the earth's magnetic field (at an angle of about 62° with the horizontal). Rotate it continuously as was done in I (*c*), recording again the number of turns per minute and the deflection of the galvanometer, if any. How does the current induced compare with that in I (*c*)? Explain the difference, if there is any.

III. Set the coil as in I, and rotate it continuously at a rate either one-half or twice as great as in I (*c*). What effect do you find a change in the rate of rotation to have upon the value of the induced current?

IV. Repeat I (*c*) with the axis of rotation vertical, rotating

the coil as nearly as possible at the same rate. To what component of the earth's magnetic field is the induced current proportional in this case? To what component was it proportional in I (*c*)? How might the angle of dip be calculated from the observations made in this section and in I (*c*)? Using a table of natural tangents, calculate thus the angle of dip at Berkeley.

V. By varying the angle of inclination of the coil, find a position for which there will be no current induced when the coil is rotated. Read the angle of inclination, if the earth-inductor has a graduated circle. What is the relation between this angle and the angle of dip? How does the value of the angle of dip found in this way compare with that found in IV?

VI. Turn the base of the earth-inductor through 90° and rotate the coil continuously about a vertical axis, as in IV, at the same rate. How do you find the induced current to compare with that in IV? Explain the difference, if there is any.

VII. Answer the following questions and give reasons for your answers:—

1. Would there have been any current induced if the coil had been moved parallel to itself?

2. Would there have been any current induced if the coil had been moved parallel to itself with a strong magnet in its neighborhood?

3. What would be the effect on the induced current if a soft iron core were placed within the coil of the earth inductor?